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Museums and ICT.
A green perspective

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ABSTRACT OF MASTER'S THESIS

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A museum is a cultural entity whose aim is to conserve, organise, study and research as well as give access to precious tangible and intangible heritage assets of society. The online museums will be realised through the combined use of design, information technology, computing resources, and community collaboration. Through the next generation museums it is also possible to improve our use of energy resources, by focusing on sustainability and allowing us to research and analyse the relationship between the digitisation of cultural heritage and energy consumption. The key target of this thesis is to understand the energy consumption of certain museums derived acts such as digitisation, long term preservation and media exhibits. Furthermore the results of a survey collecting the view of 3 museums in Finland about green ICT and museums is presented.

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Abbreviations and Acronyms

ICT	Information and communications technology
NFC	Near Field Communication
GLAM	Galleries, Libraries, Archives, and Museums, the cultural heritage institutions
LED	Light-Emitting Diode
OLED	Organic Light-Emitting Diode
CRT	Cathode Ray Tube
HVAC	Heating, ventilation, and air conditioning
OAIS	Open Archival Information System
SSD	Solid State Drive
VRML	Virtual Reality Modeling Language
API	Application Programming Interface
RFID	Radio Frequency IDentification
QR	Quick Response Code

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Chapter 1

Introduction

A museum is a cultural entity whose aim is to conserve, organise, study and research as well as give access to precious tangible and intangible heritage assets of society. It is a repository of human creations: art, objects, artefacts, books, audio, video etc. With the advent of new technologies museums have adopted technology as a medium to help achieving their goals, mainly educational, but they could also use the technological advancements to improve the energy efficiency of their operations.

1.1 Motivation

The green ICT research project at Aalto University studies energy consumption and emissions from the use of Information and Communication Technology (ICT) in different organisations and industries [1].

The energy consumption and emissions from Information and Communication Technology (ICT) is globally equivalent to that of air traffic, and is growing rapidly. The main goal of the green ICT research project within Aalto University's Energy Science Initiative is to find innovative techno-socioeconomic solutions that could lead to a major energy and environmental impact.

As part of its work, the green ICT research program is interested in studying energy consumption patterns in museums. Museums are interesting to study because they are long-lived institutions of great importance to society in conserving and presenting cultural heritage, and because sustainability in the energy needed to maintain and present their assets both physically and through the use of ICT technologies into the longer-term future may be an organisationally important objective. Setting sustainability objectives for

[1] http://energyscience.aalto.fi/en/research/projects/green_ict

their operations is an increasingly important objective for museums such as the Smithsonian and the Victoria and Albert museums[2].

1.2 Research questions

These are some of the research questions this thesis would like to address:

- What is the breakdown of energy consumption at examples of several different types of museums?
- How does the energy consumption from use of ICT compare to non-ICT energy usage?
- How to quantify and measure energy consumption for ICT-intensive processes such as:
  - Content digitisation
  - Long term preservation
  - Electronic media displays and exhibits

1.3 Research goals

The main topic of this thesis is to analyse and study the energy consumption on museums and how their derived acts such as digitisation, long term preservation and media exhibits impact their energy consumption. Every issue is then studied and a case study is presented. The goal of the case studies is not to give an exact final outcome on the topic but to give a simple approach to it so they can be studied further and have a solid base. Furthermore, to understand more about this topic we conducted a survey on three different museums that help us to further delve into this topic and see how those example museums view the topic of green ICT in museums.

1.4 Structure of the Thesis

The thesis is composed in different sections, giving an overview of the different topics:

- Introduction

[2] http://www.vam.ac.uk/content/articles/s/v-and-a-sustainability/

- Background
- Digitisation
- Long term preservation
- Media exhibits
- Survey
- Conclusions & Future work

In Chapter 2, an overview is given on how IT has helped museums to enhance and expand their goals and audiences, with emphasis on making a museum visit more accessible and educational for a general audience.

In Chapter 3, a review of the state of the art is presented on the topic of digitisation, detailing the efforts made in Europe on this topic and presenting a case study with a semi digitised robot to scan small documents and the energy cost associated to it.

In Chapter 4, long term preservation of artefacts is an important part of the role of museums and other cultural heritage institutions, and an outlook of the challenges and its costs is presented. We also present a case study that compare different methods to preserve artefacts and their related costs.

In Chapter 5, we take a look into media exhibits by analysing the different screen technologies and their energy consumption. We also present a possible model for improved energy consumption in museums that rely on PC-driven media exhibits.

In Chapter 6, we present our results from the 3 different museums to help us understand how they see this topic.

Lastly in Chapter 7 we present our conclusions on this topic and future work that can be done.

Chapter 2

Background and related work

This chapter contains a brief overview on how museums have approached the use of some new and emerging ICT technologies. It gives an outlook of some the different technologies that museums have used plus trends in the near future that may be deployed in museums. It serves as basis on how ICT has been already a prominent part in museum activities and also the fields that have been studied in the museum scene.

The NMC Horizon Report: 2012 Museum Edition [27] describes some technologies expected to become mainstream in museums in the near future: from mobile apps to Internet of Things. It gives a good overview of the new technologies museums will adopt in the near future. Determining which ones can provide a better experience to museum visitors is also an important research field. Also, one sign of the importance of this topic is the conference MuseumNext[1], where trends in museums and case studies on how museums apply new technologies are discussed.

Over the last few decades, museums have been trying to attract more visitors to their facilities. One of their action plans has been to offer new ways for visitors to interact with the museums. By the use of new technologies, visitors can have a more tailored and enriching experience if they choose to do so. It also provides a chance to visitors to have an easy way to be part of the museum experience.

The different sections of this chapter will focus on different technologies that have been and can be deployed in museums. It's not an exhaustive review but is a quick overview on the same main trends that can be seen emerging in museums around the world.

[1] http://www.museumnext.org/

2.1 Museums and ICT

2.1.1 Virtual museums

Virtual museums try to emulate the museum experience either by offering part of their collections on their websites or by creating virtual environments that recreate a museum or a place that a visitor can navigate through.

2.1.1.1 Online collections

Recently, one of the most notable efforts to provide art collections online is the Google Art Project[2]. In this case Google has partnered with museums to offer their collections online. The user can easily browse between the different museums collections, collections created by other users or create her/his own collection. Paintings include extra information such as size, technique used or information behind the depicted scene. Although Google is well known for its search capabilities, in this case the search functionality of this website is rather basic. Search is restricted to keywords and at the time of writing there's no possibility to have advanced search functions like by art period or other metadata.

Apart from the Google project, another recent outstanding example of virtual collections is the Rijksmuseum museum's website[3]. In this case we can see the paintings with explanations but it also offers advanced search features that allows the user to search for certain periods or locations. It also provides an open API (Application Programming Interface), making accessible their online collection for all of those who are interested. We will review APIs in a corresponding section later.

2.1.1.2 Virtual environments

Another approach to virtual museums is the recreation of a museum in 3D. In the early 1990s it was a popular choice to have a representation of museums and their collections in CD-ROMs [25]. With the advancement of the web and more powerful computing resources, we can find nowadays websites that recreate museums within the web browser [50] thanks to web standards such as VRML, although it's not widely used. In all of these cases they offer a recreation of the museum physical space and the user can walk through the hallways of the museum. This environment provide more information about the artefacts than in the physical museum since space is not an issue. They

[2]http://www.googleartproject.com/

[3]https://www.rijksmuseum.nl/en

also usually use audio and/or video explanations of the different artefacts shown.

The use of Virtual Reality (VR) is also a common way to provide users with enticing new experiences. The user wears goggles that make a total immersion into the virtual space. Another technology is Augmented Reality (AR), where a virtual representation of the artefact exists in the real world and the user can interact with it.

The MediaLab laboratory in Aalto has several projects that use these technologies. For example the recreation of the Finnish pavilion at the 1900 world fair in Paris[4] is a virtual environment where the users can explore the inside of the building. Feedback has been very positive and it's the only way to see the pavilion nowadays.

2.1.2 Mobile apps

Mobile applications, or "apps", typically need to meet some organisational objective of a museum: better exhibit presentation, increase visitor engagement, offer a different way to explore the collections held, etc.

Before the rise of the new mobile platforms such as Android or iOS, there have been a long history of efforts in including handheld devices in museums, so visitors could have a better experience while they visit the museum. One recent example is Tesoriero et al. [53]; they presented a system based on PDAs and its deployment. The PDA devices were interesting but museums normally would have to provide to their visitors these devices, leading to external costs of buying the devices and making the proper maintenance on these devices.

With the rise of the new smart phones and app stores such as the App Store or Google Play, museums often publish companion apps that provide more information for the user. One of the most interesting is the Smithsonian; dedicated apps for certain exhibitions that complement the information already shown at the museum[5] and expand on offering the users more ways to engage with the exhibits. They are available for iPhone, Android and also have mobile version of their website so they can reach as many people as possible. The general app has information about the exhibition, and it also allows users to share photos or comments about artefacts. They also have more specialised apps that focus on certain exhibitions and can have a dedicated style that suits more the exhibition held. Furthermore they offer a scavenger hunt app to discover the museum, so users can have a more

[4] http://paviljonki.mlog.taik.fi/

[5] http://www.si.edu/Connect/Mobile

interactive and fun way to explore the museum.

Also the American Museum of Natural History has a really well crafted app[6]. It includes turn-by-turn navigation inside the building. As the Smithsonian app it features the different exhibitions and tours that the visitor can see. It also offers sharing exhibitions through popular social networks.

In [55] there are a few more example of mobile apps in the context of museums. Templeton presents different example on how engaging museum visitors thorough the use of mobile apps [52].

In my opinion, mobile apps are a great step to have a more exciting relationship with the museum's visitors. Deployment in these scenarios is cheaper than previously thanks to users willing to use their own devices. The main problem is crafting an app that can catch the attention of the user to download and use it and if it's useful enough for continued use. Also it can provide sharing opportunities that can promote the museum to other audiences and expand their reach from the usual crowd.

2.1.3 Interactive museums

Kiosks in museums have been an important part for visitors to interact with the different artefacts displayed in a museum. Vom et al. [58] published a case study in the use of kiosks in The British Galleries at the Victoria and Albert Museum in London. The audience was more engaged to the artefact but it also had some issues. The main drawback was that kiosks are used by few persons at the same time due to space constraints, this creates queues to grab the usage of the kiosk. Also if the kiosk is located on the way to the piece, people who just want to see the piece can be disturbed by those who are using the kiosk. That's why now museums are creating new experiences that can be used directly in the visitor's phone, this way there's no dedicated space to kiosks and users can roam freely.

RFID tags are still used by a large number of museums. Apart from providing location information, it's usual that they are also used for offering more information about the artefacts. This setup normally assumes that the museum needs to have RFID readers available to lend to their users.

QR codes are comparable to RFID tags but in this case users can use their mobile phones with a camera and an app than can read QR codes. In this case it's important that museums offer their WiFi credentials so users can have a reliable way to access to the Internet.

NFC tags are also a way to have the same functionality as QR codes or

[6]http://www.amnh.org/apps/explorer

RFID tags. For example, the Museum of London [7] uses NFC tags so users can learn more about certain pieces. Having a NFC reader in the mobile phone is not yet as common as a camera (currently iOS devices don't have a NFC reader) but it's easier for the users to interact with NFC tags than QR codes. With QR codes the users have to do more steps to get to the information (have their camera active and focus properly on the QR code). Meanwhile with a NFC tag, users just have to tap the NFC tag and they will be able to access to the info.

2.1.4 Audio/video technologies

Audio guides have been a de facto standard in museums. They have been present from 1952[8]. It's an interesting solution for certain visitors, but many of the users don't like the lack of interactivity and the passive approach. Also, users find it difficult to discuss different pieces of art if they are visiting the museum with her/his friends or family. Still, it's one of the most populars choices and it has been proved successful for museums.

Videos are also another way to enhance the museum experience where the museums want to provide more information about the artefacts. Like the audio, they could be more interactive and visitors don't have the chance to decide how much they want to invest in watching the video or if the video content is interesting enough.

2.1.5 Navigation inside museums

Determining the location of a user inside of a building is a real challenge. GPS is not a feasible solution because the reception inside buildings is often lost. Museum visitors rely on paper guides that allow them to plan routes and try to find locations themselves. Recently there have been interesting technological developments in this area which don't rely on GPS that museums can apply.

One of the most common technologies deployed in museums are RFID tags. Normally users carry an RFID reader (lent by the museum) so if the user wants to know the location he just has to read the nearest RFID tag. Then the location is shown on a 2D map. This approach has been well tested in museums and there are multiple deployments of this technology but it has some drawbacks. First, deploying RFID readers for all visitors is expensive for the museum. Also it doesn't offer any kind of directions to places and just

[7] http://www.museumoflondon.org.uk/Explore-online/mobile-apps/NFC.htm

[8] http://musematic.net/2009/05/19/about-that-1952-sedelijk-museum-audio-guide-and-a-certain-willem-sandburg/

shows the location to the user. There have been several deployments in this area [20]. In my opinion, this technology is already outdated and museums are starting to use other alternatives.

Many recent developments have been done using WiFi as an indoor positioning technology, sometimes using the network infrastructure already present in some museums an accurate location can be computed by triangulating the WiFi antennas of the access points with known locations. There are several competing technologies: WiFiSLAM, Meridian or Cisco System Services. Disadvantages of this approach are that a network infrastructure is needed. There are many examples of deployments of these technologies in museums, one interesting solution is the Natural Museum of History in New York City that uses the Meridian technology (in conjunction with Cisco System Services) to provide turn-by-turn directions[9].

Apart from WiFi, there is a new technology that could be promising in the following years. Bytelight uses LED lighting to offer fine-grained location. The light acts a signal that the phone can demodulate via its camera. It doesn't need any kind of network infrastructure and they offer a mobile app that can read the signal. Price of this solution is still expensive (99$ per bulb). There is already a deployment of this technology in the Museum of Science in Boston[10]. Some drawbacks are that the user has to be located under the light and transition between the bulbs can be a problematic issue.

There's also a Finnish company that is doing work in this area. IndoorAtlas[11] uses magnetic fields to provide indoor location. It doesn't need any special infrastructure, but it needs to be set up correctly by walking inside the building (users can create the indoor maps for popular locations). They have an API that provides developers the functionality to add indoor location in their apps (currently they only offer an Android API).

Quuppa.com[12] is another Finnish startup working on indoor location using Bluetooth low energy beacons.

2.1.6 Open APIs

Open data is one of the most promising emergent trends in technology[13]. Governments and companies are introducing this concept to the information they manage. But it is also a great opportunity for museums to open their

[9] http://www.meridianapps.com/cisco

[10] http://blog.bytelight.com/post/40011523606/bytelight-illuminates-the-museum-of-science

[11] http://www.indooratlas.com/

[12] http://quuppa.com/

[13] http://opendatahandbook.org/en/what-is-open-data/

collections to the public so developers can make new and exciting projects based on the museum's data. Also it gives the opportunity to create mashups, a web page that uses content from more than one source to create a single new service displayed in a single graphical interface[14].

We presented already the website of the Rijksmuseum, apart from the online collection, developers can have access to all the information of the collection by means of an API. There have been already interesting projects like face recognition in the paintings[15] or a time line of the collection[16]. These projects provide new and enticing new ways to consume data. For using the API developers need to request a key, results of the different calls are in XML. All information of the artefacts are in Dutch.

The Brooklyn museum has also available an API for developers[17]. As the Rijksmuseum developers need to request a key and the results of the calls are in JSON.

2.1.7 Preservation technologies

Digital heritage is a new interdisciplinary field of knowledge that brings together information technology, humanities and design. Nowadays with all of the new technological advancements it's easier to preserve contemporary art, where the pieces are mainly already in a media format (audio, video, etc.). But it's also important to preserve collections that have been not digitised already and thanks to the digitisation process we can preserve old pictures or other artefacts.

There are different ways of applying this concept.

Europeana[18] is one project for the digital heritage of Europe's multilingual digital library, museum and archive. It has multiple collections from museums and organisations from the EU. It's a large repository that include different multimedia types (pictures, newspapers, books, etc.). They have an open API, the results of the API calls are in JSON. Also anyone can add material by requesting access to it. The national digital library of Finland[19] is part of Europeana network. The digitisation process is not done by europeana and is the providers who are in charge of digitising their collections. Europeana is intended to serve as a central hub to store all these artefacts.

Another project to digitally preserve old artefacts such as pictures, letters

[14] http://en.wikipedia.org/wiki/Mashup_(web_application_hybrid)
[15] http://weblab.ab-c.nl/rijksmuseum
[16] http://rm.contentecontent.com/tijdlijn
[17] http://www.brooklynmuseum.org/opencollection/api/
[18] http://www.europeana.eu/
[19] http://www.kdk.fi/en

or postcards is Project Gado[20]. It uses an open source archival scanning robot. The goal of the project is to develop a robot assistant for under 500$ dollars so small to medium archives can digitise their collections. There are some museums that have been using the robot assistant, such as the Afro American Newspapers, that have been able to digits over 120,000 photos using Project Gado[21].

As we said in the previous section, the concept of open museum is getting interesting. Crowd sourcing is one of the most interesting ideas. One prime example is Tagger[22], an effort between BBC and the Public Catalogue Foundation in the UK. Allowing users to tag the painting that can be found on galleries around the UK, permits that the visitors are an integral part of the museum experience. If we mix the idea of digitising artefacts that belong to communities and from crowd sourcing there are plenty of interesting ideas that can span and can help to preserve a large amount of old pictures.

Finally, we also have to consider the different implications; technological and cultural, of storing these artefacts. Which format should be used? Which procedures have to be followed? What artefacts are worth of storing? Who is in charge of preserving all the data? These questions belong the digital heritage field and research and different projects are trying to understand and find answer to the previous questions.

2.1.8 Energy efficiency

Museums generally have special constraints about what can be achieved with respect to energy efficiency. Normally the artefacts have to be kept at certain temperature and humidity conditions in order to preserve them and display them. Recent research shows that certain things could be considered in this respect [35], Mueller et al. presents different methods to reduce the energy footprint of the Kolumba Art Museum in Cologne, for example skylight with movable shading devices or geothermal cooling and heating .

So if one can't address all of the big picture, one can take a look at the areas where we can be more efficient and more green. As we saw, with the advent of mobile guides, paper maps or guides can be kept to a minimum so we lower a bit the energy footprint.

Aspects where technology can greatly enhance the energy efficiency of museums:

- Can we make a framework for a comparative study between the energy

[20]http://www.projectgado.org
[21]http://projectgado.org/afro-american-newspapers/
[22]http://tagger.thepcf.org.uk/

consumption of a physical museum and a next generation museum (virtual, distributed, online, tech-intensive)? In terms of energy efficiency: Where is the energy spent?

- How does a robotic scanner (see Chapter 3) and a participatory museums affect the energy efficiency of a museum? What does deploying new emerging technologies to museums mean and how they affect the sustainability aspects?

- How can we make embedding metadata open and participatory? How would linked content work with museum archives and data from eCommunities? Does metadata participation and participatory archival processes entail energy savings?

- Could there be eco tours or more efficient guided visitor flow so there aren't huge concentrations of people at the same place int a museum at the same time?

Not all of these aspects are considered in this thesis but they can be a starting point for further research in this field.

2.2 Benefits

Applying new technologies is nowadays a crucial part in the goals of a museum. Conferences like MuseumNext show that there's interesting in researching further how to apply new technologies to the museum experience. Also it's important that more engaged visitors will result from more interesting experiences and recurring visits to museums [12]. Certain museums are already applying this to attract more people to their exhibitions with interesting results[23].

2.3 Challenges

Embracing new technologies in museums can be difficult because they lack different factors that can influence the implementation. The technological part is definitely one key issue and museums need guidance and assistance. Small museums that don't have a lot of funding could be problematic though there are affordable solutions nowadays. We think that one important feature

[23]http://www.nytimes.com/2011/03/17/arts/design/museums-pursue-engagement-with-social-media.html

in the near future is the power of crowd sourcing and developing sustainable practices in museums. Allowing visitors to be part of the museums and to be able to define what they are interested in is a great opportunity for all types of museums.

Having a cross-disciplinary team is an integral part for success, we need people from different backgrounds to have a good overview on the challenges that we have to overcome. Finally having an immersive user experience is the final touch for having a completely success system. One of the best examples of how museums can embrace technology is the Cleveland museum[24]; they rely heavily on large multi touch screens so visitors can interact with the collections in a easy way.

Visitors are the last piece of the puzzle, according to Falk division [18] every visitor has a different purpose when they go to visit a museum. Recognising these type of visitors is difficult. One way to overcome this is to offer a wide array of choices so that the visitor can have the experience that she/he wants. Feedback from the visitors is important and getting it right is very useful to improve. We think that having pilot programs is a way to deploy new experiences and have honest feedback from visitors. The biggest problem is the lack of resources to have this continued approach where only big museums can iterate these new ideas.

2.4 Related work

Even though the use of technology in museums has been a very studied subject in academia ([7]), a green perspective hasn't been extensively studied and reported on so far. Much of the related works we could find were about climate in collections and making HVAC systems more energy efficient ([56] [6]). Others took a holistic view (involving architects, engineers, etc.) to reduce energy consumption [35]. Sadly this approach is very costly and not all the museums can go through such drastic renovations to improve vastly their energy efficiency.

There are some approaches that use wireless sensor networks to improve energy efficiency on museums. In [15] and [57] they have an extensive coverage in real time of the museum's climate thanks to sensors around the museum facility. The results of their studies help as a baseline to reduce the energy footprint of the museum in the future, helping them to compare different approaches.

One reason why the literature may have neglected the study of energy

[24]http://localprojects.net/project/gallery-one/

usage and ICT energy consumption on particular in museums could be the widely held assumption that museums have very specific energy requirements that have to be met so they are able to preserve their collections and artefacts without damage, and maintained in proper environmental conditions for this purpose. This narrows the areas in which technology could be applied to improve energy efficiency. In this thesis we will take a look on some of those areas that have been not covered extensively in literature.

Chapter 3

Digitisation

Digitising or digitisation is creating an object, image, sound, document or a signal (usually an analog signal) by a discrete set of its points or samples. The result is called "digital presentation" of the object[1].

Digitisation is nowadays a crucial process used in museums. With the goal of preserving their collections, museums have been eager to digitise their collections (e.g. [54], [41], etc.). It also provides them the opportunity to publish their collections publicly on the Internet so researchers or other interested individuals can study the published artefacts easily and with no need to go physically to the museum location.

There have been efforts in this area for a long time [51] and with the advent of cheaper scanners and high-quality digital cameras more museums are interested in digitising their inventory either in-house or outsourcing it to other companies.

In this chapter we will give an overview of the subject, trying to answer some basic questions such as what artefacts are digitised, how much it costs and the challenges involved in the process. We will also present an energy view on this subject, that through the surveyed literature, at the moment of writing, it seems to be a somewhat neglected topic. As a case study we present the findings on the energy cost of running a digitisation robot for small museums and other cultural organisations with limited budget.

3.1 Digitisation materials

Museums host a vast number of artefacts and different materials. We could classify some major types of artefacts a museum can have in the following broad categories:

[1]http://en.wikipedia.org/wiki/Digitizing

- Human-made objects
- Natural materials
- Works of art
- Books
- Photographs, small clippings, postcards, etc.
- Video/Audio

Nowadays one goal of a museum is often to digitise all the artefacts in their collections as much as possible but due to the different nature of the objects, that goal is still often hard to reach. For example, digitising human-made objects (e.g. vases, sculptures, etc.) is hard, it requires special equipment such as 3D scanners that are not still affordable for most museums and staff that has to be trained; it has a high initial investment. Some museums approach the digitisation of such objects with only pictures, but in this case they are not properly digitising the artefact and merely keeping an inventory.

Books have been one field where digitisation has been very prominent [14] [44]. Efforts such as Google Books[2], have tried to digitise entire national libraries. Most books can be converted to document files since it's important to be able to search easily, but also some books or written documents have importance on the object itself (due to the handwriting, written notes on it, etc.) so having images of it it's also a important part of book digitisation.

Digitisation works of art and photographs are now easier to implement than ever due to the better equipment available currently (cameras, etc.) so they can have a better digital representation of the painting or the photographs.

For audio and video, depending on the format is stored in, the only thing to do is to convert it to a digital format. Restoring and correcting some of the visual artefacts that usually appear can also be done, but the quality of the audio or video will generally be similar.

Now we will review the different techniques used for digitisation currently. We have to take into consideration that with more artefacts already being in digital format these days, digitisation will be not required in the future as much as it is needed today. Also with the current trend of 3D printing, even man made objects will have a perfect 3D model already since one is necessary to print it.

[2]http://books.google.com/googlebooks/library/partners.html

3.1.1 3D scanning

There have been projects using 3D scanning where they detailed their experiences using them such as [30],[28] or [54]. In [13], they already determine that 3D scanning is a mature technology that will improve rapidly over time and cultural heritage institutions should evaluate acquiring 3D scanners for their artefacts.

3D scanners can be divided in:

- Active optical devices: these scanners emit some kind of radiation or light over the object and reconstruct its geometry by checking how the light is reflected. There's different techniques such as triangulation or time-of-flight. The the data collected by the lasers is compiled and a 3D model is generated. These devices are expensive since require specific hardware but the quality is very high.

- Passive optical devices: where simple cameras can be used and by taking a lot of pictures of the different sides of the object by using algorithms the object can be reconstructed as a 3D model. These devices are cheaper since they rely on simple digital cameras but the quality of the 3D reconstruction is not as good as the active optical devices. One advantage of this approach is that it can reconstruct much larger objects or entire buildings whereas active optical devices would be inviable.

Nowadays, active optical devices can be found for around $800[3] for hobbyists and small objects, the energy consumption of that scanner is around 25W. But most sophisticated that can scan furniture or sculpture is around $10.0000-$20.0000[4], their energy consumption is also around 25W. There are many more scanners that were not covered.

Passive optical devices are around $4.170 [5] including the software and DSLR cameras for reconstructing from pictures to 3D models.

3.1.2 Scanning

Scanning is more widely available and cheaper than 3D scanning due to the longevity of the technology. There are specific scanners for books or for film negatives. Scanners nowadays have a wide range of resolutions to scan from being for consumer scanners around 1200 dpi or more advanced 2400 dpi.

[3]http://store.makerbot.com/digitizer

[4]http://www.artec3d.com/hardware/artec-spider/

[5]http://www.shapecapture.com/Soft_Sales.htm

Sometimes, museums need more specific scanners since the normal scanners have problems with fidelity or acquiring range. In [45], Shi et al. developed a specific scanner to overcome some of those challenges. Currently, museums tend not to use scanners anymore and instead tend to use more sophisticated set ups with DSLR cameras that can take pictures with higher resolutions and usually faster than using a scanner.

3.1.3 Digital cameras

Currently with the advancement of DSLR cameras, it's possible to take high quality pictures of pictures or other material prone to this kind of digitisation. It's the main approach for museums due to its low cost, easily available equipment and general software such a photo editing tools to correct visual artefacts that could appear on the digitised representation. Also, the workflow is easier than scanners since pictures taken are immediately available, improving the workflow efficiency and the speed.

3.1.4 Analogue to digital conversion

In this case, we talk about audio or video formats that are stored on particular formats such as vinyl records, phonographs or film reels. For this purpose, organisations need special equipment to do the digital conversion, often is outsourced to other companies specialised in this kind of conversion.

3.2 State of digitisation

The recent survey report on Digitisation in European Cultural Heritage Institutions (2014) [49] gives a good overview on digitisation in Europe. Around 36% percent of the cultural institutions surveyed have written a plan about digitisation. Also more than 50% of artefacts they own have to be still digitised and catalogued properly. We are talking about a large quantity of material to be digitised

Europeana is an EU project that acts as central repository for the european cultural heritage. Its aim is to aggregate, facilitate, distribute and engage. Currently it has several ongoing projects to digits from contemporary art to manuscripts[6]. It's one of the main forces in Europe for digitisation and it's an effort between different European projects from the technological field and the humanistic field.

[6]http://pro.europeana.eu/projects?p_p_id=projectindexportlet_WAR_europeanaportlet_INSTANCE_1mpE&p_
2&p_p_col_pos=1&p_p_col_count=2

In the U.K., there's also a large group dedicated to digitising national collections[7]. Their funding comes mostly from institutional organisation across the U.K. and a smaller amount from private institutions such as universities.

In the U.S.A., the Smithsonian museum has been one of the most prominent and open about their process since they have been involved in this field during its inception and being one of the early pioneers. They have enforced a digitisation plan [46] from 2010-2015. Though digitisation is expensive and it requires effort, the advantages of it are numerous according to the Smithsonian report, such as broading access, preserving collections, support for education and enrich context.

3.3 Costs

The average annual budget for European museums' efforts on digitisation is around €98.000 [49] for all the museums that participated in the survey. Half of this budget comes from the institution itself and the other half is from temporary funding from governments or other organisations.

The general costs of digitisation can be divided in two big categories, according to [49]:

- **Incidental costs** are defined as the costs involved with the initial creation or acquisition of a digital collection. Examples: selection of materials, acquisition of digital born materials, scanning, etc.

- **Structural costs** are the costs needed for the ongoing maintenance, enhancement and preservation of a digital collection. Examples: activities concerning the preservation of digital collections, licences, maintenance of web servers, user outreach and support, management.

According to the survey those costs are comparable and take the same part of the digitisation budget (50%) of the institution.

Further the incidental costs can be divided in these different activities [49]:

- Analogue to digital conversion
- Metadata creation
- Project management
- Web design, software development

[7] http://www.jisc.ac.uk/whatwedo/projects.aspx

- Selection of material for digitisation
- Logistics
- Acquisition of digital born material
- Copyright clearance
- Other costs

39% of the incidental costs are for doing the digitisation process. 19% are dedicated to the metadata creation.

Table 3.1: Costs of digitising museum collections. Source [39]

Material	Lower estimate(€bn)	Higher estimate (€bn)
Human-made objects	4.76	25.92
Natural material	5.75	26.72
Works of art	1.36	7.39
Photographs	1.89	3.67

Table 3.2: Costs of digitising different items. Source [39]

Material	Lower estimate(€)	Higher estimate (€)	Mean (€)
Human-made objects	-	-	121
Natural material	26	121	73
Works of art	25	136	80.50
Photographs	4	15	12

In Table 3.1 there's an outline on the costs of digitising the different types of materials that museums have. The individual cost for each kind of item can be further seen in Table 3.2.

3.4 Challenges

As we can see from the previous sections, digitisation is still a costly and difficult process, and as such there's still challenges that need to be tackled.

3.4.1 Cost

One of the main challenges is cost, either in time or money. Although the Smithsonian and other cultural institutions highly value digitisation and see that the benefit is more than the cost, small institutions can have a lot of problems implementing digitisation. This can't be overlooked, although we strongly believe that with the advent of new technologies that digitising processes can improve, so it could be made more affordable for any kind of institution regarding less of its size.

3.4.2 Digitisation process

The digitisation process in itself is also challenging. Most of the organisations have specialised needs and it requires to create tailored software. The diverse array of artefacts that some institutions have is also an enormous problem. Paintings are more easy than objects such as relics that have to be digitised in 3D. Also setting up the proper practices for digitisation is needed such as making sure that the digitised version of the artefact has enough quality and it doesn't have any errors. Most of the digitisation processes in Europe are done by the institutions themselves, though more specialised objects can be outsourced to companies that have the proper equipment and procedures to manage the objects properly.

On the other hand, thanks to the rapid improvement of technology, each year the hardware becomes more affordable for institutions and new solutions appear that can me make more appealing to the institution start their own digitisation department.

3.4.3 Formats and quality

Another challenge, is the quality of the digitisation. Digitising for the future means trying to store the artefact with the highest quality possible. In the case of books, you can easily store just the text (although in some cases the book itself could be interesting enough to digitise in itself). Pictures or paintings have to be digitised using large resolutions. 3D scanning has also to be done properly and with a high number of polygons to have a good representation of the artefact with the highest fidelity. Having a pipeline in place for a digitisation plan is an important step.

As an example of a digitisation plan and the formats and qualities usually required in such projects, we can take a look to the Partage Plus Project[8], an European project to digitise most of the art nouveau pieces that European

[8]http://www.partage-plus.eu/

museum have in their collections. In this project digitisation involves a large array of artefacts from vases to artworks. Uncompressed video and audio is recommended, also open source formats are preferred. 3D artefacts are more complicated since there are no leading standards. In this case the Partage Plus project uses .obj format to save them though to publish them online 3D PDF is used since it allows quick access and small file sizes.

3.4.4 Digital access

One benefit of digitisation is the possibility to publish the digitised artefacts on the Internet as open content, freely accessible and with possibilities to use it. But sometimes it can't be done due to copyright issues; since not enough years have passed to be copyright free, sometimes they also extend the copyright of certain works. These kind of issues were already brought to the attention when more and more museum published their collection using CD-ROMs [4]. Fair use is usually cited for those who think that works of art should be copyright free but it depends on a case by case approach [32].

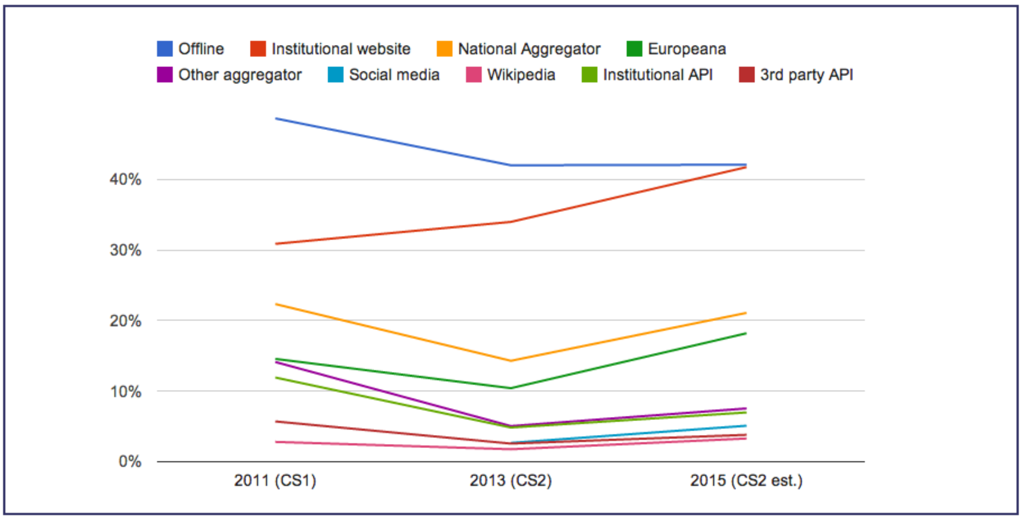
Even though the benefits of publishing the collections museum online are well known [47], some institutions can be reluctant to publish their collections online due to fear to cannibalise their own visitors directing them to their digital collections instead of visiting physically the museum.

Regarding how the collections are accessed, in Figure 3.1 we can see the percentage of the cultural institutions whose collections were made accessible through different access channels across Europe. As we can see offline access is still very prominent (around 40%), followed closely by the institution's website.

3.4.5 Long-time preservation

As a final challenge, storing and preserving the digitised artefacts is crucial. The formats used for storing the digitised artefacts are critical, due to the long term preservation goal, the format has to be chosen carefully so they can ensure that it can be viewed in the future properly. Also, the digitised artefacts need to be high quality, since digitisation is costly. We will talk more about this on Chapter 4, where a detailed overview on this topic is given.

Figure 3.1: Percentage of the collection accessible through different access channels. Source [48] and [49]



3.5 A green perspective on digitisation

As we could see from the survey [49], the costs of digitisation are mainly calculated as incidental costs and structural costs as previously presented. In neither of those, there is a consideration of the energy consumption for the process of digitisation, either in the short term or the long term.

Calculating the energy cost of the digitisation process is relatively straightforward, although it varies greatly depending on the process used for digitising the artefacts. Installing energy meters on the devices used for digitising is enough to have a nice estimate on how much energy it cost to digitise an artefact. However the author has not found reports or papers on this subject. Later in this section we present our case study using this technique. The next step is how we can improve the energy efficiency of digitising. One way of considering this issue is using devices that are already certified [9] as energy efficient. Most scanners have already such certifications in place already.

We can also think of digitisation as a way to a greener museum experience. If artefacts that are hard to access or need specific equipment to check them (such as gloves or special rooms) are digitised, researchers and the public wouldn't need to go to specific museum to study them, lowering the travel footprint. Also with the advancement of 4K screens, museums can share their collections easily and instead of carefully transporting the artefacts with the

[9] http://www.energystar.gov/index.cfm

impact for the artefact and the travel that causes, they can just display it in a high resolution screen, giving the same feeling to the audience as from a real painting.

On the other hand calculating the energy impact once an artefact is preserved is much harder as we will explain more in detail in Chapter 4.

3.6 Case study: Digitisation with the digGLAM assistant

3.6.1 Introduction

The digGLAM assistant (see Figure 3.2) is part of a joint collaboration between the MediaLab at Aalto and the Data Communication Software department.

The digGLAM assistant is based on the Project Gado[10], a semi automated robot to digitise printed material items. As a part of my work, a UI was developed to easily interact with the robot so small museums or organisations could easily use it and scan part of their collection with little intervention. Furthermore, functionality was expanded and testing tools were added for a easy setup.

One goal of the project was to quantify the energy used in the robotic assisted digital scanning of artefacts. The measurement setup is shown in Figure 3.3. Four energy meters from a company called Plugwise[11] were used; they measured AC electric power at different points of interest: 1) Total, 2) laptop, 3) robot + powered USB hub for its USB powered components, 4) scanner and webcam powered via a second powered USB hub. In the following sections, we have assumed that the loss at the power strips (kept as short as possible) and at the Plugwise measurement units is negligible.

3.6.2 Setup

In this case, we measure the different components of the digGLAM assistant and the total. We separated our system in the following parts: the laptop, the robot (including the power source and the USB hub), the scanner and webcam (including the USB hub) and then the total of the previous components.

[10]http://projectgado.org/digglam-alpha/

[11]http://www.plugwise.com/

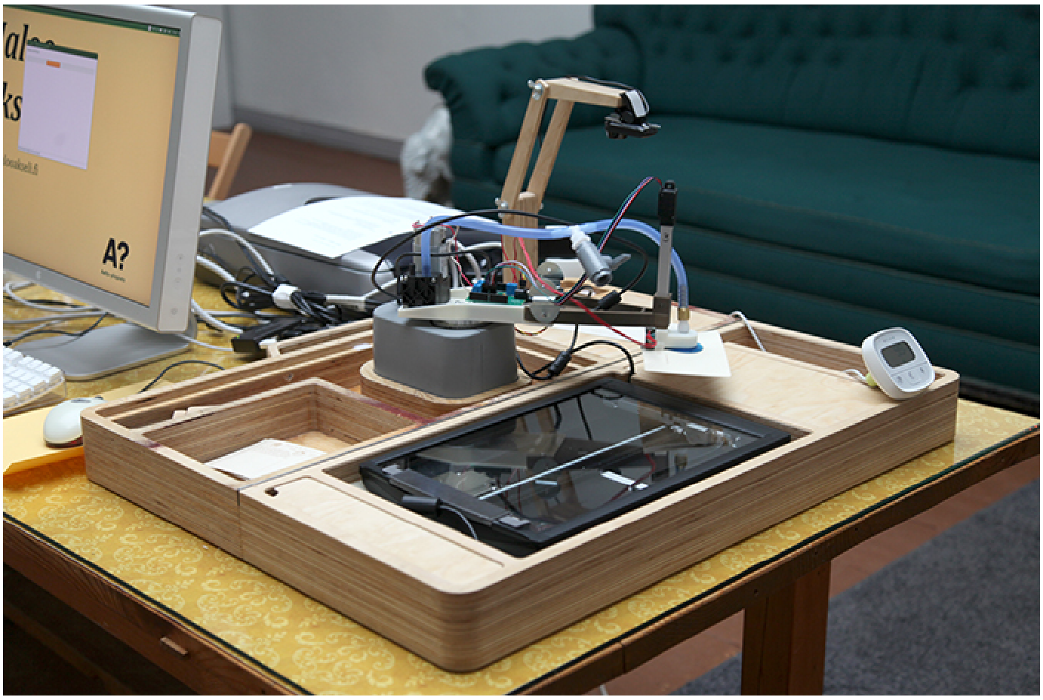


Figure 3.2: The digGLAM assistant

3.6.3 Results

The overall energy consumption of the different experiments are shown in Figure 3.4. Over the course of a typical digitisation run the laptop consumes about 50W, the robot about 10W and the different peripherals (webcam, scanner and USB hub) around 8W. The total is around 70W.

One metric that we found interesting to estimate is the energy cost to digitise one artefact; in our case a single postcard using the digGLAM assistant.

Helsingin Energia's price for electricity in January 2014 was about 0.142 EUR / kWh (including 24% VAT). It should be noted that this price contains two components that were roughly equal: Electric Energy Cost and Electricity Transfer Cost.

If we constantly run the robot plus laptop for one hour of digitisation, that is about 0.07 kWh for the theme day. Using the Helsingin Energia's price mentioned before, the energy cost of that one hour of digitisation is then estimated to be about 0.00994 EUR (including 24% VAT). In one hour, the digGLAM robot scanner system can scan around 70 postcards (one-sided) according to our experiments. So the energy cost of digitising each one is then around 0.0001342EUR (including VAT). The cost of digitisation is quite

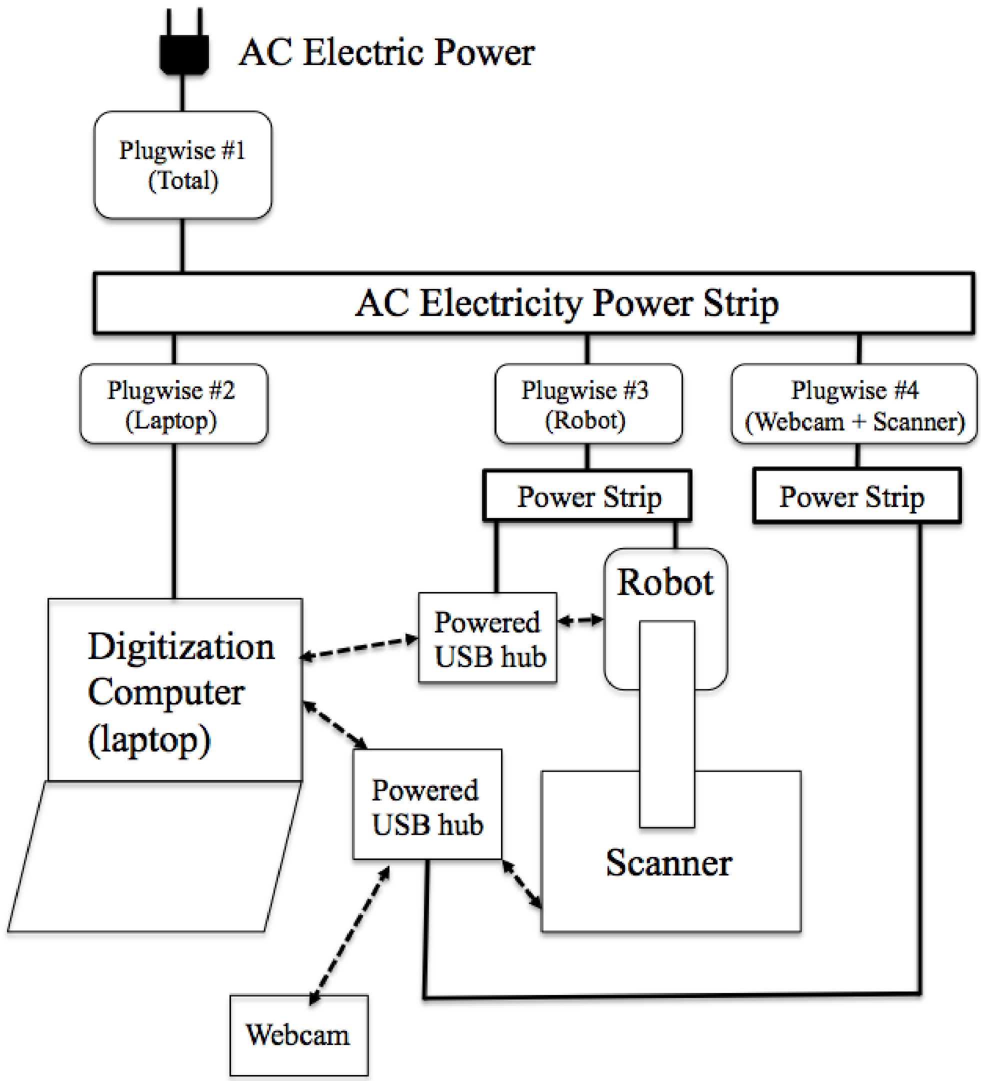


Figure 3.3: Setup for the digGLAM assistant

minimal.

This estimate does not include any energy costs associated with post-processing of the image or of storing data in the cloud, just the robotic digitisation and saving the image onto the computer.

The results show that digitising using the digGLAM assistant is not expensive and the cost per artefact is quite low compared to other systems that require a more attentive approach. Also the use of consumer devices, makes the system extremely affordable and thanks to the modularity of the system different scanners and webcams can be used. The robot is the only piece

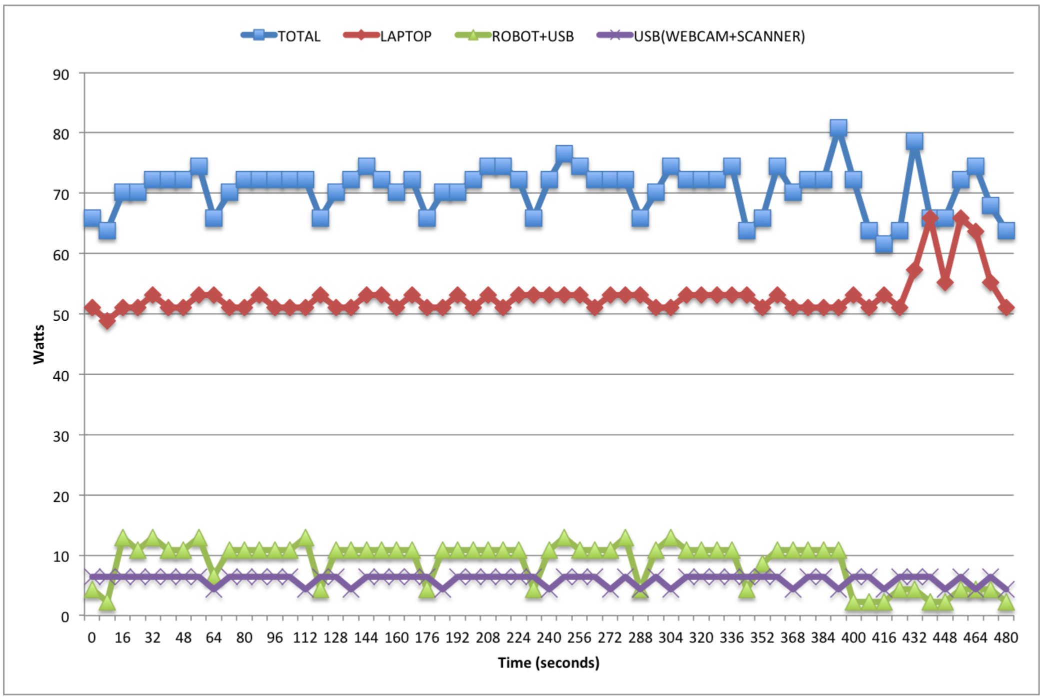


Figure 3.4: Energy consumption for the experiment

that is hard to replace if it gets broken and requires repair. We were able to fix the small problems we found along the way. It's important to notice that consumer devices, such as the ones used in this experiment, are getting more energy efficient so the energy consumption of the laptop, webcam and scanner will decrease over time.

The cost of digitising is an interesting metric and showing the energy consumption and informing the public about it, it's a good practice; it is important since they can have a good overview of the energy footprint for digitisation. Although one of the main advantages of using the digGLAM assistant is the possibility to run it without any assistance so the staff have more time to work on other duties. Also we have found that is a great tool to bring to museums, audiences were easily engaged due to the nature of the device and the project often caught the attention of the visitors.

3.7 Conclusions

Digitisation is a still ongoing process that will take several years to be fully adopted by most of the museums and other organisations. Although the digitisation process in Europe is strong and there have been a lot of projects involving the adoption of this technology, some of the challenges presented in this chapter still have great relevance in the near future. Copyright issues could be an important hurdle for organisations if it's not studied in detail. Also, long-time preservation will be further studied in Chapter 4.

The case study is a small example how the energy footprint could be studied in this field. Measuring the energy of the different devices can give a good overview of the energy footprint. The explicit costs were detailed, implicit costs such as post-digitisation process and salary of the people working were not taken into account, since it depends on different parameters that were out of scope for the case study.

Finally, digitisation is the main force for preserving the heritage and artefacts of older, current and future generations and therefore, in our opinion, one of the most interesting fields for technology to help and enhance the energy footprint.

Chapter 4

Long term preservation

As we described in Chapter 3, one of the main challenges of digitisation is storing and preserving artefacts for future generations so they can be easily accessed and viewed by the general public. Museums and other organisations are in charge to protect and preserve their artefacts. With the advent of new technologies more and more artefacts have been digitised or are digital artefacts to begin with. This results in museums needing new set of principles to store and preserve digitised artefacts so they are preservers properly for future generations.

Digital preservation has been a prominent issue since 1994 when the Task Force on Digital Archiving in the US was born. It acknowledged the importance of preserving the cultural heritage and in 1996 they produced the first report [59]. Most of the early challenges were about what is worth preserving since in those days storage space was still scarce and expensive. Also digitisation was expensive and costly [29]. Thankfully, nowadays, we have solved most of the storage space problems thanks to the rapid advancement of technology and we have plenty of storage space to preserve digital artefacts. Still, the green aspect has been currently overlooked.

In this chapter, an overview of different preservation plans is presented. We will outline the challenges on long term preservation and the energy impact of this topic. Finally a case study is presented, where energy consumption is studied for two different approaches local storage and cloud storage.

4.1 Preservation strategies

Feeney et al. in [19] divide digital preservation in the following ways:

- Preserve the original software (and possible hardware) that was used to create and access the information. This is known as the technology preservation strategy. It also involves preserving both the original operating system and hardware on which to run it.

- Program future powerful computer systems to emulate older, obsolete computer platforms and operating systems as required.This is the technology emulation strategy.

- Ensure that the digital information is re-encoded in new formats before the old format becomes obsolete.This is the digital information migration strategy.

Technology preservation and emulation strategy are focused on digital documents or computer programs since you still have to run or read them using special equipment. Museums don't often follow these strategies since they merely have digital representation of the artefacts. Instead they focus on migration.

There have been several recommendations for preservation system for museums. For example, Yeung et al. [62] give some broader recommendations to museums when outlining their preservation plan. The main focus is to have a policy set that is enforced since technological change are inevitable and commitment to the policy is the only thing that will remain steady through the years.

OAIS (Open Archival Information System)[1] is the standard used in long term preservation. It's a framework that was originated in space agencies but it is now widespread in many different organisations. For museums and other cultural institutions it has become the standard model for digital preservation. An overview if the system can be seen in Figure 4.1.

There are many projects to preserve digital heritage around the globe. National libraries have been always leading in the field of digital preservation. In [8], Beagrie et al. conducted a survey pointing out future challenges for national libraries, the main issues were formats of the files and having a set of policies for long term preservation implemented.

In Finland, the Ministry of Education and Culture as part of their National Digital Library project (KDK) is leading the efforts with the CSC to offer long term preservation[2]. They are providing the necessary infrastructure and also direct support to all cultural institutions across Finland so they can submit easily their digitised artefacts. This will be also included in the Europeana project that is being carried across the European Union.

One of the latest efforts with the cloud on mind is [40] where Rabnovici et al. present a system that takes advantage of all the cloud solutions currently

[1] yeung2004digital

[2] http://www.csc.fi/english/csc/news/news/kdk-dp

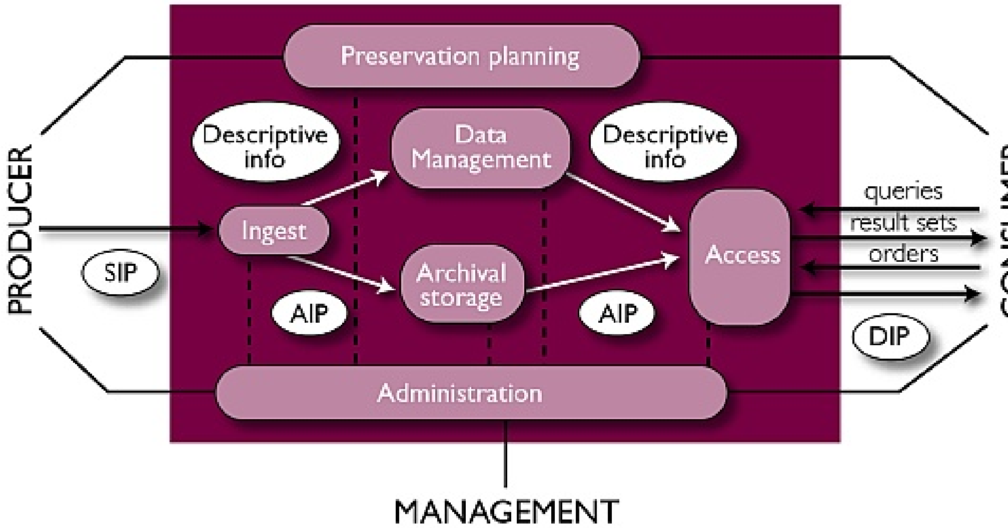


Figure 4.1: OAIS framework overview

available. They provide an interface that is able to interact with most cloud providers so organisation can use the power of the cloud in an easy way. They use the OAIS framework as base for their system, following the rules and principles to offer long term preservation.

4.2 Storage mediums

Storing artefacts in a safe way so they can be accessed later if needed is one issue that preservation plans face currently. In this section, different storage mediums will be compared and what storage mediums are present in digital preservation plans.

In 2008 the National Archives of U.K. made a report on how different storage mediums compare to each other in terms of long term preservation goals[3]. They were compared using the following criteria:

- Longevity
- Capacity
- Viability
- Obsolescence

[3]https://www.nationalarchives.gov.uk/documents/selecting-storage-media.pdf

- Cost
- Susceptibility

Linear Tape Open got the highest score under the previous criteria. Although some solutions can carry problems with problems like migration since they have to constantly migrate from one medium to another. Also the durability of medium storages such as CD-R and DVD-R are not suitable for long term preservation. On our literature survey we see that many cultural organisations and museums use optical mediums like hard drives since it's easy to read and write and migration is a bit easier than other storage mediums such tapes. Also, redundant back ups are also necessary in preservation, since it's not affordable to lose any data.

4.3 Costs

There have been some literature studies about the cost of long term preservation. In [11] a comparison of two different services (Harvard University Library and the Online Computer Library Center, Inc.) is presented, noting that audio and video are the most demanding formats for storage solutions and text as the cheapest format to store.

In [61], Richard Wright et al. describes the best approach for long term preservation: "Starting with a simple strategy is frequently the best approach. One way to reduce the cost of risk, and hence the best chance for mitigation of loss, is simply not to compress the data. Storing only uncompressed data would appear to add cost rather than reduce it - but storage costs are typically a small part of a preservation project or strategy (labour is always the dominant cost), and storage media cost is dropping by 50% every 18 months". The cost of medium storages will definitely decrease over time thanks to technological advancements.

In [42], Rosenthal et al. compare several providers, concluding that cloud storage is not yet feasible since is much more expensive to have your archive on those services due to retrieval costs and the amount of data to be transferred to the cloud service.

As Figure 4.3 shows, the cost of ownership of a hard drive, electricity is the lowest of all the parameters analysed. Therefore electricity is not a major parameter on long term preservation. Moreover, with more energy efficient storage mediums such as SSDs getting more popular, this will even lower over time. Labor, device and infrastructure are definitely the major decisive costs involved in long term preservation.

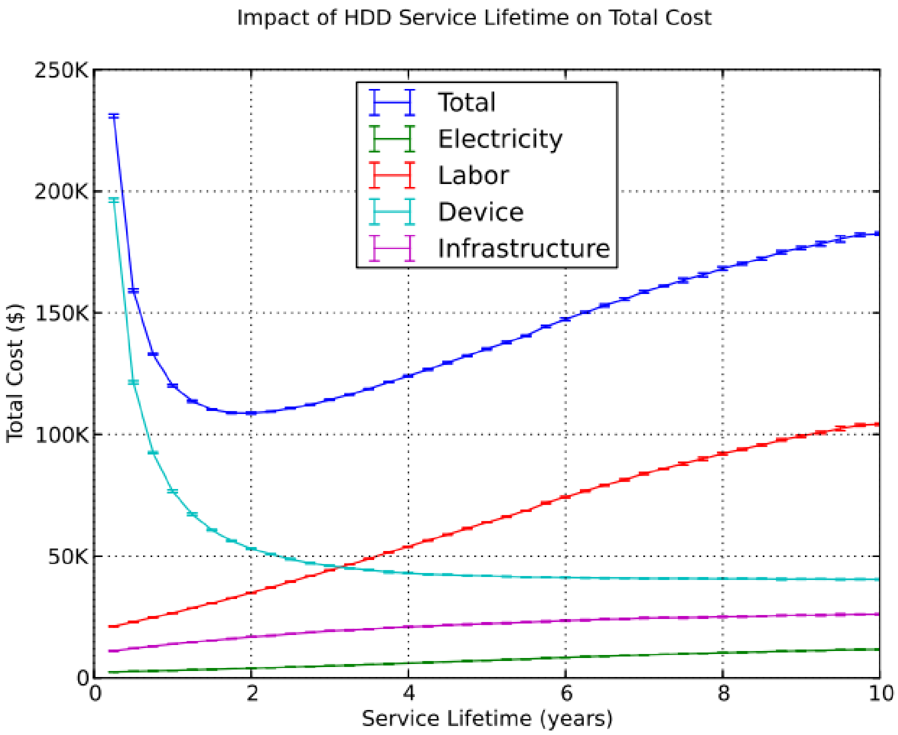


Figure 4.2: The effect of hard drive service lifetime on 10-year cost of ownership of an archive growing 57%/yr. Source [42]

4.4 Challenges

Digital preservations is a very important topic. Being able to preserve digitised artefacts is crucial since losing the digitised artefact will incur digitising the artefact once again and in some cases where the artefact may even be damaged or lost over time to not being possible to digitise it again.

4.4.1 Copyright issues

As presented in Chapter 3, copyright is still a grey area in most of the preservation plans surveyed. The Europeana project, previously commented, demands that all artefacts are delivered with a free license. With old artefacts (hundreds of years old), it's not a problem (although pictures of those artefacts can have copyright) but with recent artefacts (last century) it could be an issue since the copyrights for some artefacts may be in a grey area. In some of these cases where the copyright is still a problem, usually organisations are allowed to preserved them but maybe they don't have the rights to distribute or publish them on the Internet and other formats.

We believe that in the future new regulations and laws will be legislated so these issues can be easily solved by museums and other cultural institutions.

4.4.2 Data lock-in

Data lock-in is an important issue since some organisations can't provide their own infrastructure for their preservation plans, they have to rely on third parties that provide this service, meaning that the organisation depend entirely on their service providers. This could be a problem if the service provider goes out of business or other potential problems arise. The organisation must anyways ensure that they can easily and reliably retrieve their data.

This challenge could be overcome if cloud providers make standardised APIs so customers have the possibility to use them so they can easily move between providers or just recover their data in a systematic way across providers.

4.4.3 Discovery and access

The amount of artefacts stored in preservation systems will definitely increase over time. Managing the amounts of information and being able to make it discoverable for everyone is an important issue that still has to be tackled.

The OAIS framework takes into account discovery and since most preservation plans follow this system, it is already considered by most museums.

Since preserved artefacts are rarely accessed and its retrieval could be slow and costly, most museums have low resolution copies of digitised artefacts so they can be easily published in the Internet and accessed by the public.

4.4.4 Migration

Migration is defined as "...a set of organised tasks designed to achieve the periodic transfer of digital materials from one hardware/software configuration to another, or from one generation of computer technology to a subsequent generation." [59].

Migration is a critical part of long term preservation. As the storage mediums degrade and/or need to upgrade to newer and more powerful mediums, migration has to be done. The chances of corrupting data while migrating can be quite high and the need for in-place systems are more than necessary.

In [60], Wheatley et al. present an overview of the different issues that organisations have to face when migrating their data. Comparing different data from documents to computer programs, they compare how migration will be carried in these different type of documents.

4.4.5 Metadata

Metadata comes hand in hand with discovery since a powerful metadata system will be definitely help discovery of artefacts. Complete preservation plans have very fine detail information on the metadata that has to be in the project. Although due to some organisations using their own systems, converting the metadata to one format to another is still a problem. Also migrating to new metadata system has to be considered in case of providing information to third parties.

4.4.6 Cost

Long term preservation is a costly activity since it's an ongoing activity that doesn't have a specific end. Systems have to be reliable and endure many years of use. Creating one system to replace another for a decade may not be not a good approach since the cost of data migration and other issues are not negligible. Robust and plans that are revised and enforced constantly are mandatory if an organisation want to successfully preserve the artefacts.

The Europeana project estimated that from 2010 to 2015 they will double the amount of artefacts stored in their systems, this will have to be provisioned properly.

In [24], Hinton et al. analysis the energy efficiency on the Internet, presenting different estimates on how the energy is consumed through the Internet. In the case of downloading a file, storage is constant and transmission and the energy cost of the servers are the one that lineally increase over time during the transmission.

4.5 A green perspective on digital preservation

If there's one area that green computing can help, it's definitely in long term preservation. Data centres are getting more efficient over time and storing and retrieving digitised artefacts can be done cheaply these days. One big drawback is since not many organisations can afford to have their own data centres and infrastructure, they have to rely on other that provide them the service. On the one hand it frees the organisation of acquiring and managing more staff and infrastructure, but on the other hand they don't have the complete control and this could cause certain problem. In my opinion, the benefits are very important for certain organisations, and that a centralised system should be provided by different government or organisations in different countries. As we presented Europeana is a huge effort that involves all cultural institutions across the European Union. It is also trying to give a centralised solution and storage for all cultural institutions across Europe.

Bostoen et al. [9] conducted a survey of the latest trends regarding energy efficiency on data centre storage systems. They review different technologies like using newer SSD drive or new algorithms to improve the energy efficiency of reading cycles from a hard disk. These solutions usually come with a tradeoff or work under very specific use cases. There was no use case in particular with long term preservation on mind.

Although data centres have been improving their energy efficiency, some could argue that the trend of energy efficiency in hard drives have not followed the same trend[4]. In [21], Guerra et al. discuss about improving the energy efficiency of hard disk by energy proportionality designs. In their simulation they were able to achieve energy savings of 40%-75%.

There are ways to improve the energy efficiency of storage and in upcoming years we will see more and more ways to do it.

4.6 Case study: Long term preservation storage

As the challenges section presented, data lock-in can be a very important issue that is hard to overcome since recovery or service provider failure means you don't control your own data. In this section we will compare two different approaches for a small-medium organisation, either having their own storage in place or handling to a third party storage provider.

We will describe the pros and cons of each approach and give an estimate on the energy and monetary cost.

4.6.1 Cloud storage

Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks,

[4]http://searchstorage.techtarget.com/news/1285060/Is-storage-top-energy-hog-in-data-centers

servers, storage, applications, and services) [34].

Storage solutions have been reviewed heavily in literature, for example in [5], Armbrust et al. compare different parameters to analyse the costs to move data to the cloud. In cases where huge amounts of data have to be stored every day in a cloud storage solution, uploading and processing that data to the cloud can't be as fast and convenient as a local storage.

Amazon solutions are one of the most popular choices. They have two different storage solutions: Amazon S3 [5] and Amazon Glacier [6]. In this case we will only review Glacier since it's main point is to offer long term preservation of data.

The Amazon Glacier service is designed to enable customers to efficiently and reliably store unlimited amounts of archival data at low cost, with high durability (i.e., designed to provide average annual durability of 99.999999999%), and for long periods of time. This is a good solution for preserving information in the long term that has not be retrieved often such as artefacts that have to be preserved. According to some sources[7], they have set their own custom solution using custom hard drives to achieve long durability of the component and low energy impact. Others think that they use special optical mediums[8].

The main issues with this approach is the time needed for recovering and storing artefacts on the cloud, the retrieval rate speed can be a bottleneck in time critical situations. Also, retrieving data from Glacier is more expensive than S3. Data lock-in is definitely present since Amazon is in charge of your data without you have any control over it, customers don't even know what system Amazon have in place. There also issues regarding the safekeeping of a country's "national identity" data to providers like Amazon.

The benefits of using cloud storage is the simplicity since you just have to upload the information. The organisation doesn't have to invest in an infrastructure and it's a very scalable solution.

There are also other approaches to cloud computing supported by projects like Europeana, CloudLo that provides to small and medium organisations the tools they need to ensure their digital preservation plans such as cloud storage.

Lastly, the energy consumption in these cases is hard to give an estimate though we can safely assume that they are highly energy efficient. Also for the organisation using these services, the cost of energy would be while transferring the information and not exactly by hosting the hard drives.

[5] https://aws.amazon.com/s3/
[6] https://aws.amazon.com/glacier/
[7] http://mjtsai.com/blog/2014/04/27/how-is-amazon-glacier-implemented/
[8] http://storagemojo.com/2014/04/25/amazons-glacier-secret-bdxl/

4.6.2 Local storage

On the other hand one can use local storage solutions. They have benefits such as faster backup times and faster retrieval times. As cons, we have to take care of redundant back ups and replace older or faulty disks with other disks. We also have to take care of migration and it's not very scalable since we will have to acquire more disks to store more information.

RAID is a system that was first described in 1988 [37], using normal hard drives we can have a system that is fault tolerant and provides with transparent backups. It provides organisations features like mirroring and also fault tolerance. One of the benefits is the low cost of the solution since consumer hard drives can be used very easily.

Local storage has several drawbacks such as having to invest in infrastructure and maintenance of the storage. Furthermore, organisations have to be in charge of migration and error failure. This is very time consuming and if they didn't set robust procedures it can cause that all data could be lost, unacceptable in this kind of situations. Also it's important to have off site backups in case something happens in the location where the hard drives are located.

The energy cost of this set up is also quite low, desktop hard drives consume around 6W under load and 4 while idle. If one would like to improve the energy efficiency of the setup, RAID and other setups can work with SSDs drives. These devices consume up to 2W under load and 0.5W while idle.

4.7 Conclusions

In the seminal paper from 1997 [23], Hedstrom et al. already gave a complete overview of challenges and different areas of research that could help to investigate further the topic of long term preservation. Areas such as storage media, migration, conversion, and management tools were considered the decisive fields that will help to achieve the goal of long term preservation. Some of them have been studied extensively in different papers and studies or also already overcome thanks to new industry standards. On the other hand there are some topics like migration and management tools that are still issues in long term preservation plans. Besides, topics like energy efficiency and costs may have not been on the spotlight when studying this topic.

One of the most popular recommendations for museums through the literature surveyed has been the implementation of plans and policies for long term preservation. Having a plan in motion that is constantly revised and set is one of the most important tasks that museums have to do. Ensuring that plans are being followed properly is even better than focusing on technological solutions since rarely technological solutions rarely work for a limited time span, while correct policies are set for a much longer time period.

In the case study, a comparison between cloud storage and local storage was considered for small and medium museums. The energy consumption of the two different approaches is quite low. Also nowadays thanks to the European Union investing in long term preservation by launching projects such as Europeana that helps smaller museums to stay updated in new technologies. Sadly, the energy consumption in this solutions have not been a priority so far, but we think that in upcoming years more and more emphasis will be put in this area trying to reduce the energy consumption of the storage.

Technological advancements can definitely help to make long term preservation more energy efficient. We feel that with storage mediums being more energy efficient and with new ways to make data centres reduce their energy footprint, there is still a long way to develop a truly green solution. We need solutions that make long term preservation a reality, so future generation can access to millions of artworks or other artefacts that will be lost if we won't make that effort.

Chapter 5

Media exhibits

Media exhibits are often a big part of museum exhibits, since it allows them to present the exhibition information better, make interactive works of art, teach extra information about a subject, etc.; by using them the audience feels more engaged and it gets to participate actively more on the museum [22]. The first appearance of the use technology in a museum is from 1952 and by the end of the 20th century all major museums employed handheld devices or other technological advancements for attracting more visitors to their museums [10].

These kind of media exhibits rely mainly on displays connected to PCs or other devices such handhelds, tablets, projectors, etc. Certain type of museums are more prone to use media exhibits for their purposes such as contemporary museums, for video art pieces or science museums, where interactive installations using novelty technology makes possible to engage audiences better and make them learn more about certain science topics in a fun way [43].

In this chapter we will look into the different displays technologies (one of the main components of a media exhibit) comparing their energy consumption. Some challenges associated to the use of these technologies will be presented from an energy perspective. Finally we will study how technology is helping or can help to reduce energy consumption in media exhibits, furthermore a case study where we present energy efficient alternatives for museums that rely heavily on this kind of exhibits.

5.1 Display technologies

Displays are the main part of media exhibits. Museums use a different array of displays for their purposes, from TV screens, to computer monitors or projectors.

We can categorise the display technologies in two broad groups, that can be further divided depending on the technology used to display the images:

- Screens
  - CRT (Cathode Ray Tube)
  - LCD (Liquid Crystal Display)
    - CCFL (Cold Cathode Fluorescent Lamp)
    - LED (Light-Emitting Diode)
  - Plasma
  - OLED (Organic Light-Emitting Diode)
- Projectors
  - DLP (Digital Light Processing)
  - LCD (Liquid Crystal Display)
  - LCoS (Liquid Crystal on Silicon)

5.1.1 Screens

CRT is the oldest technology and mostly not used on newer screens. Though it is possible that it's still used on museums due to their constrained budget to switch to newer screen technologies. Compared to the other screens, CRT shows the highest consumption of energy[1].

LCD screens are now predominant on newer displays, it has different backlighting technologies that can improve their energy efficiency. LED backlighting is the most popular and the power consumption is around 10-20% of a CRT screen. The power consumption of an LCD screen is constant and there's no variance except for the brightness level.

Plasma screens' power consumption varies on the amount of light is needed. So to show a bright image in a plasma screen will consume more than a darker one. This parameter makes it difficult to compare it directly with other screens but on a broad note, it's safely to assume that plasma screens are not as efficient as LCD screens.

OLED are the most energy efficient due to the fact that an inactive OLED element does not produce light or consume power. Another benefit is that can show true blacks. Still OLED screens are not widespread as LCD screens

[1]http://www.tomshardware.com/reviews/lcd-backlight-led-cfl,2683-8.html

and on certain conditions (with white backgrounds) they even consume more power than LCD screens. Mostly OLED screens are located in smaller devices due to the technicalities in creating large screens with this technology, although recently there have been improvements in this area with 50 inches OLED screens.

A good reference for energy efficiency on screens is Energy Star, a U.S.A. Environmental Protection Agency voluntary program that identify and promote energy-efficient products to reduce greenhouse gas emissions. The rating help customers to choose energy efficient products that comply with the strict regulations of the agency.

As a reference of energy consumption current we present a compilation of the most efficient screens lately reviewed by this organisation at the time of writing (the yearly consumption has been estimated for being on around 4 hours per day):

- The most efficient screens under 20 inches consume around 8-18 kWh per year[2].
- Computer Monitors 20 to 23 inches consume around 16-24 kWh per year[3].
- Over 23 inches from 19 kWh up to 75kWh[4].

Regarding televisions' energy efficiency, the most efficient energy televisions at the time of writing are using LCD technology with LED backlighting (the yearly consumption is based in 5 hours use per day):

- Televisions under 35 inches consume 19-46 kWh per year[5].
- Televisions between 35 to 50 inches consume yearly around 54-85 kWh[6].
- Televisions over 50 inches consume 97-112 kWh per year[7].

5.1.2 Projectors

Projectors on the other hand don't have Energy Star ratings so it's hard to know which ones are more energy efficient the others. Manufactures have in

[2] http://www.energystar.gov/index.cfm?c=most_efficient.me_comp_monitor_under_23_inches
[3] http://www.energystar.gov/index.cfm?c=most_efficient.me_comp_monitor_20_to_23_inches
[4] http://www.energystar.gov/index.cfm?c=most_efficient.me_comp_monitor_over_23_inches
[5] http://www.energystar.gov/index.cfm?c=most_efficient.me_tvs_under35_inches
[6] http://www.energystar.gov/index.cfm?c=most_efficient.me_tvs_35to50_inches
[7] http://www.energystar.gov/index.cfm?c=most_efficient.me_tvs_over50_inches

place green features that make projects more energy efficient such as stand by mode or auto brightness. We can give an overview on the most popular technologies mentioned in the last section and list some of the latest projectors so we can have a better grasp of their energy consumption.

Lamp projectors have an energy footprint of 410W (DLP projector with lamp), 330W (LCD projectors) or 350W (LCoS). Some DLP projectors don't need lamp, therefore they have lower energy consumption and less heating generation than other projectors using lamps. This kind of projectors use around 250W-350W[8] when operating and stand by mode just 0.4W. More benefits are the lower maintenance and the instant turn on and off of the projector.

5.2 Challenges

Media exhibits or interactive installations have plenty of challenges that we will describe in the next sections.

5.2.1 Heating

Big projectors or using a large amount of screens and PCs in the same area can increase the temperature in a room considerably, causing the HVAC system to work to keep the area at a comfortable temperature. Keeping the temperature constant no matter the circumstances causes more CO2 emissions and increases the energy bill of the building [38].

5.2.2 Brightness and illumination

In OLED screens, the energy consumption of a pixel is related to its brightness and colour. Iyer et al. [26] have developed energy-adaptive display subsystems that help reduce the energy consumption of such screens without impacting the usability of the interfaces by using dark backgrounds.

Another interesting case is [17], where Englert et al. developed a system for improving the energy efficiency of large LED wall screens, that given the number of people watching the screens and the natural light around it, it is possible to save up to 25% of energy.

[8] http://www.casioprojector.com/products/Pro_Models

5.2.3 Robustness

Digital media exhibits are forced to use robust systems since installations run an average of 10 hours per day. Due to the heavy use of the components, the life span of these devices can be severally reduced. For example, the lifespan of a projector is measured by the lamp usage. Lamp projectors usually last around 2000 hours, assuming that projectors will be running for 10 hours every day, the lifespan is 200 days. That's not a very ideal situation if we consider that they are the most expensive components of a projector. The last section showed that there are alternatives with lamp free projectors but usually they are more expensive and they have poor viewing range, making them most suitable for smaller environments.

5.3 A green perspective on media exhibits

One of the first things museums can do to improve their energy efficiency of their media exhibits is just to keep renewing their displays and devices. As [36] points out, energy efficiency on TV screens and other displays is improving rapidly over time. With energy efficiency improvements TVs and screens are also getting more technological features (higher resolutions, better contrasts, etc.), that will make digital media exhibits more appealing in the near future.

Thanks to the rapid development of technology, most of the screens currently in the market are Energy Star compliant, making it easy for consumers and organisations to be energy efficient when buying new equipment. Also, with new displays technologies such as the LED backlighting for LCD screens, the energy of the screen has been reduced severely being nowadays only a 10-25% of an old CRT screen.

Apart from technological improvements that lower the energy footprint of devices, we can take a look on how technology can help to reduce the energy footprint. A 4K screen is not a new display technology but is just a new resolution that is available. Most of 4K screens use LCD display technology but OLED will be also available in the near future. Energy can be around 460W in typical use[9]. In [33], Masaoka et al. performed subjective assessments to compare images and real artefacts under certain conditions, using high resolution screens and other techniques to present the images, observers couldn't find notable difference between the image and the real object. One could predict that by using this kind of screens, the need for transporting and lending artworks to other museums will decrease over time since visitors

[9] http://www.planar.com/pdfgen/2505/ur8450-lx-2505.pdf

wouldn't be able to distinguish any differences to the real artwork from a certain distance and with proper lighting. This will help to preserve better artworks since they don't have to be transported around and save CO2 emissions for the travel of these artworks.

Other cases like the Van Gogh museum uses the same kind of technology to present 3D realistic paintings of Van Gogh so audiences around the world can see near perfect representation of the original artworks without the need to go to Netherlands[10]. It's important to note that in cases where almost perfect representations of original artworks will be available to the public, museums have the obligation to inform visitors that they are representations and not the original pieces.

5.4 Case study: Framework for switching to greener media exhibits

As a part of studying further the energy consumption of exhibits, we will present a simple framework that takes into account new devices that can substitute screens or PCs connected to those screens. But first, we will describe our case scenario and the difference after we put into effect the improvements explained.

5.4.1 Case scenario

In our case scenario, a science museums is presented where most of the installations have screens attached to them.

The number of installations is 100, where 70 of them are composed of a screen and a PC, 20 large screens (television screens bigger than 40 inches) and 10 projectors. Exhibits run for about 10 hours every day. We assume that most of the PCs and screens were bought in early 2000s and the museum board has decided to upgrade the equipment in the exhibitions area. One of their goals for their new exhibits is reliability but also improve the energy efficiency.

For our case study, the devices considered are PCs purchased in late 2007[11], a LG TV from 2008[12] and a Sony projector from 2007[13]. Table 5.1

[10] http://www.vangoghmuseum.nl/vgm/index.jsp?lang=en&page=327966

[11] https://secure.www.upenn.edu/computing/resources/category/hardware/article/computer-power-usage

[12] http://www.lg.com/us/tvs/lg-50LA6900-led-tv

[13] http://www.projectorcentral.com/Sony-VPL-VW60.htm

shows the energy consumption per device and the overall energy consumption for 10 hours a day.

Item	# devices	Device consumption (W)	Total consumption (kWh)
Display	70	32	22.4
Computer	70	100	70
Projector	10	300	30
Large screen	30	50	15
Total			137.4

Table 5.1: Energy consumption in our case scenario

In our case study we are considering two approaches: switching to iPads and switching to Raspberry Pi. At the time of writing we didn't see any papers that study these scenarios with energy consumption as a metric measured. There are reports that give an exhaustive overview of the different uses of iPads or other touch devices around the USA and how they help to engage the museums' audience [31].

5.4.2 Switching to iPad

Most of the devices in our science museum rely on a PC plus a screen to give more information or instructions to the visitors. Switching to iPads (through the use of elegant stands or kiosks set ups) could lower the energy consumption since we don't need a PC and display anymore.

As a reference for our scenario we are considering the iPad with Retina display, a tablet device from Apple introduced in 2011. Currently the price is $399. The energy consumption of the iPad in sleep mode is 0.16W, while idle with the display on is 4.57W and under heavy load we can assume that is 9.6W since the charger is 12W with an 80% efficiency[14]. The energy consumption is quite low already compared to a setup of PC + display.

In this scenario we will switch 60 PCs to iPads and we will consider that the projectors and large screens are still used. In Table 5.2, there's an overview of the new scenario.

The results shows a huge improvement of the energy efficiency on this regard. It's important to remember that all screens and PCs that are going to be renewed have to be properly recycled.

Apart from the energy consumption reduction, there are also other benefits in this kind of setup. The iPad doesn't have any movable parts or fan

[14]http://images.apple.com/environment/reports/docs/iPad_wRetinaDisplay_PER_Mar2014.pdf

Item	# devices	Device consumption (W)	Total consumption (kWh)
Display	10	32	3.2
Computer	10	100	10
iPad	60	9.6	5.76
Projector	10	300	30
Large screen	30	50	15
Total			63.96

Table 5.2: Energy consumption switching to iPads

so it doesn't generate dust as the PCs, also it doesn't heat as much as a PC, improving the energy efficiency when cooling the building. Also as we commented in earlier sections, iPads provide some sense of familiarity to visitors allowing them to start using them without any complications.

On the other hand, there are some drawbacks by switching to iPads. One would have to port all the applications running the PC to the iPad platform, although one could also do webpage based applications. In this case we will have several improvement: being able to update the application without deploying to the iPad. Also if we could still use other devices to show the same information without too much hassle. The biggest drawback of this approach it could be the price of an iPad although other tablet devices have lower price and similar functionality with low energy consumption so the option to buy cheaper devise is definitely a possibility.

5.4.3 Switching to Raspberry Pi

Another approach is to switch only the PCs to Raspberry Pis. In this case the cost of a Raspberry Pi is $35 for model B and $25 for model A. The model A doesn't have a LAN port, has less RAM and has only one USB port.

According to some sources[15] a typical setup for the Raspberry Pi model B (with peripherals such as keyboard, screen, etc.) consumes around 3.1W when idle and 3.4W when it's doing heavy CPU work. But depending on the setup and the power management it can consume as less as 2.1W for model A[16]. For our scenario we will assume the highest energy consumption, although in different setups it could be interesting to have the model A due to its low power consumption.

[15] http://www.kaibader.de/my-new-raspberry-pi/
[16] http://www.raspberrypi.org/forums/viewtopic.php?f=63&t=6050&hilit=watts+power

The overall energy consumption can be seen in Table 5.3.

Item	# devices	Device consumption (W)	Total consumption (kWh)
Display	70	32	22.4
Computer	10	100	10
Raspberry Pi	60	3.4	2.04
Projector	10	300	30
Large screen	30	50	15
Total			79.44

Table 5.3: Energy consumption switching to Raspberry Pi

The results show that switching to these devices help reduce the energy consumption of the exhibitions but a bit less than switching to iPads. This is mainly to the use of the old screens that are very energy consuming. If one would also switch to more energy efficient screens, the energy consumption will be even less that with the iPads.

The benefits of this approach is the reuse of the screens and the ability to use the same software that it was running. Raspberry Pi can use different GNU/Linux distributions and if you already developed your applications for a multi platform environment, it's not problem to make them run on Raspberry Pis. Also, the Raspberry Pi is very small and it doesn't have any movable parts as the iPad, so heat generation and dust is keep to a minimum helping improving the energy footprint of the museum.

Although Raspberry Pis are a perfect replacement for PCs on this kind of setup there are still some issues that Raspberry Pi have to fix. The most concerning issue is the corruption of SD cards when the power switch is flipped[17], this causes the impossibility to boot the system without reformatting the SD card and installing again the new system. This can't be a very good solution for highly demanded installations that have to run all day. Also powering properly the Raspberry Pi is a crucial step of the set up, USB power is not enough in most power demanding situations also an incorrect powering can damage the board.

5.5 Conclusions

Media exhibits are a big part of museums and probably more museums will widely start using a different array of screens and other devices to set up new

[17]http://raspberrypi.stackexchange.com/questions/7978/how-can-i-prevent-my-pis-sd-card-from-getting-corrupted-so-often

exhibitions because it attracts and engages museums' visitors.

Energy efficiency on technological devices has been always improving over time and we certainly believe that in the future devices will consume less and less thanks to energy efficiency on the components itself and also with appropriate energy policies on those devices.

With the upcoming 4K screens there's a perfect chance to put in to practice pilot projects where such screens are used for showing high quality representations of real artworks, this will definitely impact the way museums think about lending artworks to other institutions or different ways to present them to the public.

Finally, as we presented in our case study, there are already ways to improve the energy efficiency of museums that rely heavily on these kind of media exhibits. Switching to devices such as a Raspberry Pi or iPads for some purposes like showing extra information of the exhibition or artwork is more energy efficient (up to 50%) but it also helps engaging visitors more, therefore enhancing their museums' experience.

Chapter 6

Survey

This chapter presents the results from a survey made to three museums in Finland in early 2014. The questionnaire used plus a description of the project, was sent beforehand to all the participants. All this documents can be seen in Appendix A.

The survey was conducted as an open interview allowing the interviewers to expand or elaborate on different issues that they think relevant to the topic but inside the areas we defined with the questionnaire. The length of the interviews was about 1 hour. We thank all the participants for their time and their thoughts on this topic.

The original aim was to survey a broader set of museums, but still from this small set of respondents, there are some useful insights into the topic of Green ICT to be learned. The surveys were with an IT representative from the Finnish National Gallery covering the Ateneum Art Museum and Kiasma Museum, an IT manager and exhibit creator/organizer at Heureka (science centre), and an administrator at the Gallen-Kallela Museum. The persons interviewed had different areas and levels of knowledge about Green ICT and about the survey topics and questions asked.

In this chapter, first a summary is presented where we highlight the similarities and differences between the different museums in broader level, then a compilation of all the participants' answer is presented where we offer more detail on the different areas we focused on the interviews. Finally, in the conclusions, the results of the survey are discussed.

6.1 Summary

The museums we have interviewed for the "Museums and Green ICT" survey were diverse. The Finnish National Gallery is the largest art museum organisation in Finland, although in the interview only the museums Ateneum and Kiasma were covered. Heureka is a science exhibition centre, that focuses on the use of media exhibits with a diverse array of hardware, mainly screens and PCs, to teach science related topics. Finally, the Gallen-Kallela museum, is a small sized museum dedicated to the Finnish artist Aleksi Gallen-Kallela[1].

Even though their goals and daily operations differ vastly, there are still common goals regarding their energy patterns. All three institutions monitor (e.g. monthly) their overall energy costs (and thus consumption). The main reason is to try to save money in the long term. Energy costs, such as those associated to the HVAC system, are a significant cost and trying to be more energy efficient is a common goal that all institutions surveyed share.

The three museums agreed that the largest part of their energy budgets was destined to the HVAC system and lighting as they need to match certain conditions to preserve the artworks and their visitor's comfort. Apart from the part destined to the HVAC systems and lighting, not all the participants were not able to give an exact number on the energy consumption of their IT infrastructure. Only the Finnish National Gallery gave a rough estimate (around 1% or 2% at most of their overall energy consumption). Since they all felt that the HVAC energy consumption overpasses greatly the IT consumption, they did not feel it's very significant in the overall energy budget. Regarding the IT consumption, they all felt that since new equipment is becoming more energy efficient over time, due to technological advancements and energy ratings such as Energy Star, there's no need to take an especially proactive stance when buying new IT equipment for energy efficiency.

Currently, increased energy competition in the electricity marketplace can provide better prices and organisations, such as museums, can benefit from this opportunity. Now that such competition is starting to occur, monitoring energy consumption and costs over multiple years becomes even more important: to see if significant savings are really achieved when switching providers. Moreover, some of the electrical companies generate energy using renewable sources, this can be a factor for some museums to switch providers since this can be aligned with their sustainability goals on the long term.

One large institution (Finnish National Gallery) had a formal sustainability plan covering the years 2011-2015. However, after a large structural and administration reorganisation at the start of 2013, it remains to be seen how that will be followed up in the future.

Regarding digital media exhibits, we found that museums that hold these kind of exhibits (Kiasma and Heureka) share two main goals:

- The primary goal for media exhibits is to function according to their

[1] http://en.wikipedia.org/wiki/Akseli_Gallen-Kallela

intended purpose (showing information, video art, interactive installation, etc.).

- By aiming to make such exhibits both as simple and reliable as possible, unnecessary heat is not generated: resulting in a more energy efficient design. It is also thought that over time the different components (media players, displays, controllers, etc.) used to build new exhibits are also becoming increasingly energy efficient.

Digitisation is on the plan of all the museums interviewed in different degrees. Ateneum and Gallen-Kallela museums outsource their digitisation to specialist photographers who take high resolution pictures of the different artworks and artefacts. Both museums will also be part of Finland's project for long term preservation called Museo 2015[2] with the goal of preserving and presenting to the public all digitised artefacts in Finland.

All three institutions store their digital media in servers. The general trend was towards use of virtualised servers. The digital media stored includes many diverse types of organisational data (email, databases, network file systems, etc.) and also includes digitised representations of museum artefacts (photos, videos, etc.).

In one case, the servers were additionally backed up onto tape by the data centre used. The energy consumption for the operation of virtualised servers, tape backups, etc. was not generally known.

The large institutions measured web visitors and web traffic to their web services, such summary data was not made available for this survey.

6.2 Finnish National Gallery

6.2.1 Background

Ateneum and Kiasma are part of the Finnish National Gallery (FNG). The Finnish National Gallery is the largest art museum organisation in Finland and a national cultural institution that employs about 250 museum professionals. The museums of Finnish National Gallery are visited by about 500,000 people every year.

The collections of Ateneum covers mostly Finnish art, all the way from 18th-century Rococo portraiture to the experimental art movements of the 20th century. Part of their collection is publicly available as part of the Google Museum Project[3].

[2]http://www.nba.fi/fi/museoalan_kehittaminen/museo_2015

[3]http://www.google.com/culturalinstitute/collection/ateneum-art-museum

Kiasma is a museum of contemporary art. Its primary role is to educate the public on contemporary art and to strengthen the status of art in Finland in general [4].

6.2.2 Interview

The interview was with the IT department from the FNG and concentrated mostly on the Ateneum and Kiasma museums in Helsinki [1].

6.2.2.1 Museum energy consumption

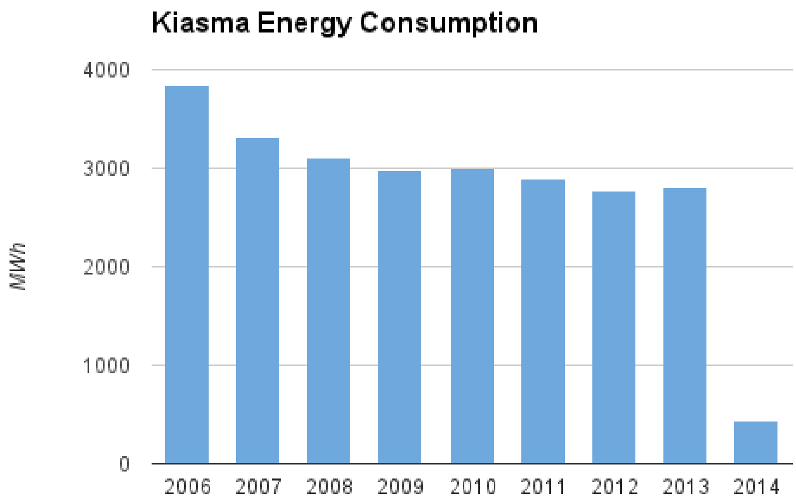


Figure 6.1: Kiasma Energy Consumption

As an introduction we were presented with the energy consumption of the Kiasma museum from 2006 to the beginning of 2014 (see Figure 6.2.2.1). Data for the Ateneum museum was only available for the period 2005-2010 (see Figure 6.2.2.1). As it can be seen from the figures, the energy consumption has decreased steadily over the past several years. Their best rough estimate was that the energy costs related to the information technology on their activities can be considered at most 1% or 2% of the total energy consumption depicted in the previous figures. This was however just an estimated guess.

[4] http://www.kiasma.fi/

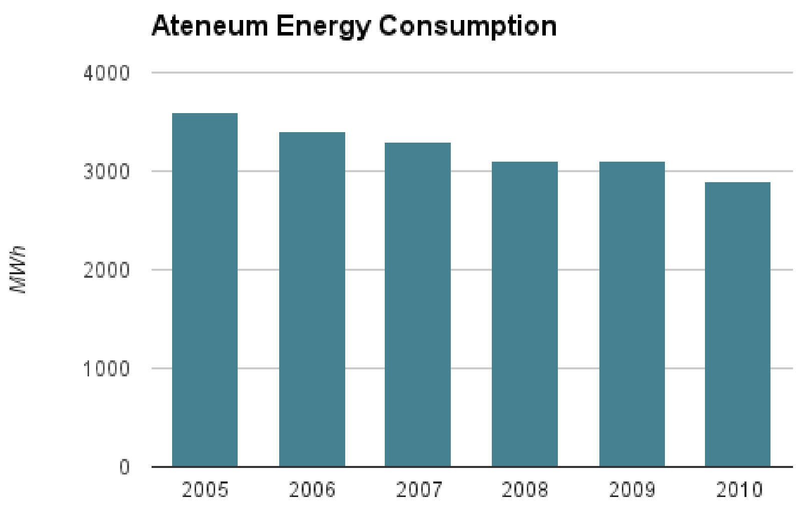


Figure 6.2: Ateneum Energy Consumption

The National Board of Antiquitites (NBA) has its own staff that takes care of maintaing these buildings.

6.2.2.2 Sustainability planning

Respecting sustainability, the organisation had a strategic plan for sustainability from 2011-2015. It may be worth noting that there were major organisational and administration changes at the start of 2013.

The biggest reason to consider sustainability is the ability to save money thanks to energy reduction. The energy consumption is closely followed to identify how to reduce unnecessary energy use to save money.

When buying new IT equipment, the IT department did not specifically analyse energy consumption for the new equipment since nowadays newer hardware is already increasingly energy efficient. They are also pushing towards mobility, by buying laptops or tables that are usually more efficient that their desktop counterparts.

6.2.2.3 Digital media exhibits

Ateneum rarely hosts any digital media exhibits. On the other hand Kiasma uses a wide array of projector or other displays to create their digital media exhibits since video art or other type of installations is a big part of contemporary art.

Regarding energy efficiency and digital media exhibits, they have to be shown in a certain way to achieve their intended purpose which results in a certain energy cost. The main goal is to have great media exhibit installations, and optimise their energy cost is often a secondary goal.

6.2.2.4 Digital media storage

Their digitisation process is in place though often slow, as they have to carefully move the pairing to prepared rooms where they usually take high quality pictures of the artworks taken with specific lighting, camera angles, etc. For storing digitised artefacts the Finnish National Gallery used to have their own servers but nowadays they have moved most of their data storage to the CSC centre. CSC stores backups in tapes.

Ateneum digitises around 100-200 artworks each year. They have 15TB dedicated to store the digital collections of which 8TB are currently in use.

Regarding digital preservation, they joined efforts in a CSC plan for digital preservation (refer to Chapter 4 for more information). They thought it possible that they may have challenges with porting all the current metadata of the artworks to the new system and that will take some time. Apart from that, they are glad that the CSC plan was started because it will allow them to have a more specialised team that will take care of the challenges for long term preservation.

6.2.2.5 Web presence

FNG museums track their web statistic using Google Analytics. However they couldn't provide us with data about the number of visitors or data traffic, which might have been useful to estimate related energy costs.

6.3 Heureka

6.3.1 Background

Heureka is a science centre located in Vantaa (Finland). It opened in 1989 and has a wide array of exhibitions, either built by the staff at the centre or borrowed from other science centres around the globe.

Heureka is an interesting case to study since it doesn't have artworks and its main focus is exhibitions through interactive mediums, such as physical exhibits or by aids of computers.

6.3.2 Interview

The interview was with an IT manager and exhibit creator/organizer at Heureka [3].

6.3.2.1 Museum energy consumption

The main energy consumption is the HVAC system. In Heureka's early years, the automated start of exhibits in he morning was staggered so that the peak load would not overload the electric system. Nowadays that is no longer a concern.

In recent years, a new HVAC system has been installed and is estimated to reduce the HVAC energy consumption by 30%-40%. It tracks the CO2, moisture and other parameters to ensure comfort to the visitors and to be energy efficient.

There isn't a central control for the exhibits since that would require adding more networking infrastructure (switches, cabling, etc.) and it would incur in problems such as additional heating of the building and more energy consumption to cool the building. Instead exhibits are connected to power panels that can be turned on/off, also each exhibit's IT is independent and self starting, since it's possible they have to do manual restarts throughout the day.

6.3.2.2 Sustainability planning

They don't have a plan per se, apart from continually renewing older devices with more energy efficient devices. They have been experimenting with replacing PCs used for exhibitions with Arduino or Raspberry Pi controllers.This is to reduce size, complexity, heat and energy. However reliability and robustness of those is not yet at the level needed for a full roll out. In Chapter 5 a simple model is presented for this kind of transition, outlining the energy costs savings using this approach.

6.3.2.3 Digital media exhibits

Heureka has around 200 exhibits. They rely heavily on use of screens and full fledged PCs for interactive guides, etc. The main goal of their exhibition operations is reliability as they have hundreds to thousands of visitors daily and in case of exhibitions malfunction it will directly impact the visitors's experience.

They generally prefer to use LCDs screens since the heating generated is not as much as a projector. Furthermore projectors have shorter lifespan and generate more heating that involves more building cooling resulting in higher energy consumption for the museum. They only have 10 large screen exhibits and their IMAX theatre involves 15 computers that take care of video and audio systems.

6.3.2.4 Digital media storage

Since the main focus of Heureka is independent exhibits that can be operated at the museum or rented out, they don't have a digitisation program in place. They mainly store the programs and videos they developed for them in their own servers. Each installation occupies around 500MB that contains mostly the audio or video resources for the exhibit.

Over time, they have moved from having 15 servers to 3, mainly thanks to server virtualisation. According to them, this resulted in a significant improvement on how they manage their servers and in heating and cooling the server room. They have 48TB of space to store their exhibitions, that is kept at the museum's facility.

6.3.2.5 Web presence

The only server they don't have in their premises is their web server. They follow analytics on their user behaviour, and find that the most frequent use of their website is to check schedules during the same day so people can decide wether to visit the museum or their opening hours.

6.4 Gallen-Kallela Museum

6.4.1 Background

Gallen-Kallela museum is a museum dedicated to the Finnish artist Aleksi Gallen-Kallela, his studio and house at Tarvaspaa was opened to the public as the Gallen-Kallela Museum in 1961; it houses some of his works and artefacts that belong to Gallen-Kallela himself[5].

6.4.2 Interview

The interview was with an administrator of the Gallen-Kallela Museum [2].

[5] http://www.gallen-kallela.fi/

6.4.2.1 Museum energy consumption

Currently, they check their energy bills (electricity and oil heating) regularly. They have recently been comparing services and offers of different electricity providers, as the increased competition in the electricity market leads to better prices for customers, so they can lower the cost of their energy bill.

A 1961 AC system was replaced in 2011, but still dramatic improvements in energy consumption are still being studied to see if there have been notable improvements. Oil heating is used mostly in the colder months.

Their energy bills have been steady for the past couple of years.

Due to the small size of the museum, they don't have a specific role for maintaining the building's facilities. In the case of IT maintenance, they use a part-time subcontractor. They have a total of 8 PCs, mainly for office work but 2 are dedicated for the catalogue system, one in the premises and one in Vantaa where they have a storage space. There's no information on the energy consumption of those PCs.

6.4.2.2 Sustainability planning

They don't yet have a defined plan for sustainability, but the organisation is green conscious trying to move to a paperless environment and recycling paper.

New equipment is bought without too much explicit consideration of energy consumption but since new devices are increasingly energy efficient they assume they will have lower energy footprint over time, lowering then their energy costs and consumption.

6.4.2.3 Digital media exhibits

Due to the size of the museum and their nature (mostly works from Aleksi Gallen-Kallela), there haven't been a lot of media exhibits. Although one interesting exception has been the recreation of the Finnish pavilion at 1900 Paris World's Fair exhibit[6]. It involved a large area of the museum dedicated to set up a projector and different controllers to see a 3D representation of the pavilion.

Occasionally there has been a video art exhibition or screens to provide more information on the exhibits. They only have one screen for the audience of the museum and most of the time is not used since they don't always have

[6] http://paviljonki.mlog.taik.fi/2012/09/22/finnish-pavilion-at-akseli-gallen-kallela-museum/

a use for it. They also have some projectors but they are mainly used for different conferences or lectures on the museum premises.

GKM has recently implemented an audio guided system where visitors can read QR codes from their smartphone to listen more about the art works displayed at the museum. For achieving this system they had to change their network infrastructure so they can provide free WiFi for their visitors, making it easier for them to use the audio guide system.

The building itself presents many challenges to use projectors. It is quite light (since it was originally an artist's home and studio) so it's difficult to make a dark enough space so projections can be seen without too much set up.

6.4.2.4 Digital media storage

Even though it's a small museum, thanks to grants from the Finnish government, they have been able to outsource their digitisation to a photography studio. It mainly consists of taking high resolution pictures of the different artworks and artefacts that the museum has in its inventory. A third of their artefacts that are in the collection management system have been digitised already. Still there's a lot of artefacts coming in from donations that have to be cataloged and digitised.

Respecting pictures, around 20% have been digitised so far. Although all digitised artefacts are stored, not all are shared through their public website. In addition there are about 1200 photos from Gallen-Kallela's time. They are not photos of objects but are rather cultural/historical photos (e.g. his travels, and his family's life, etc.). 500 have been recently photographed and wait to be digitised. There are plans to put those on Flickr under a Creative Commons license.

Their hard drive storage capacity is around 1.8TB, the utilisation so far has been 0.7TB. They keep their hard drive in the premises and they don't have any program for backup in place. They also have a smaller hard drive that is used as network drive where there day by day stuff that all employees share.

6.4.2.5 Web presence

GKM doesn't keep track of their web visitors and doesn't have yet a plan for implementing such analytics.

6.5 Conclusions

Museums are currently interested in becoming greener organisations and try to lower their energy footprint. All of the museums we have interviewed share the goal of becoming more green and are aware of their energy consumption mostly by tracking their energy bills. The biggest reason behind this is to save money as energy is expensive. Museums have certain requirements that they have to follow, so artworks and exhibitions don't get damaged due to improper climate control. This causes that the HVAC system is the most important part in their energy budget. Energy consumption of IT equipment was not very much considered since they are a small part of the overall energy budget and such equipment are becoming more energy efficient over time, though they definitely think it's a good approach to reduce the energy consumption of IT and other equipment.

Digitisation is a big part of our study and we believe that all the museums surveyed have considered this subject and their efforts into digitisation are significant. It's encouraging to see that even smaller museums like the Gallen-Kallela museum are actively digitising and considering publish some artefacts to the Internet under a Creative Commons license. Hopefully thanks to the Museo 2015 project, we will soon be able to access easily many such digitised artefacts from the Internet.

Regarding digital media exhibits, we have learnt greatly from the participants. Heureka's approach by doing a pilot program replacing their older devices with Raspberry Pi is a good example of an approach to lower the IT energy consumption in an organisation.

The survey's aim was to see the views of the museums on the Green ICT topic. We feel that it was a good starting point, being to able to see the museums' views on this topic. We have realised that large museums have more time and budget to look into their energy budget though none of those surveyed have launched a full report on their energy consumption with a detailed breakdown according to their different sub-systems (HVAC, lighting, network, IT, etc.). Smaller museums due to lack of staff or resources may not have the possibility to focus on longer projects such as their energy consumption over time. In the future, collaboration with museums is an integral part for any project that tries to study the energy consumption of these kind of institutions.

Finally, we want to thank again for the participation, time and insight to all the participants of this survey. We hope it was useful for them to reflect on some of their energy practices as well as to think of other view points that they usually don't have time to consider. We certainly think that it helped us to understand more of how a museum operates and issues that, before this survey, we didn't consider .

Chapter 7

Conclusions

Through the different chapters of this thesis we tried to address the original research question we outlined in Chapter 1. Studying the challenges and offering a green perspective on some of museums' practices, specially around green ICT, was an interesting task where so far no significant literature survey was found by the author. We think that the results shows in this thesis can be a strong foundation for later research. We will give some pointers about this on the section Future work.

Digitisation has been one of the most prominent processes where museums are currently heavily investing their resources. Preserving and curating already existing artefacts and new artefacts is nowadays often assumed as an inherent goal of museums' activities. There are projects at the European level that are pushing towards digitisation of different materials that museums host. We believe this is a great effort that will bring multiple opportunities to researchers and the general public so they can easily access to years and years of great artefacts that so far were only available by physically travelling to and visiting museums. Furthermore, digitising artefacts will also create new ways to vastly improve museums' energy efficiency since travelling to remote museums is increasingly cost prohibitive.

Long term preservation is crucial part of many museums' purpose. As more and more artworks and other cultural pieces are created, there's an increasing demand to be able to preserve securely these artefacts. There are frameworks, such as OAIS, that try to help museums and organisations to put into action a preservation plan but due to technical requirements this can be still cost prohibitive for certain museums, specially smaller ones. Thankfully there are projects, similar or in addition to the digitisation plans we've already mentioned, that help small and medium organisations to also be part of this. As we presented, a combination of local storage with tapes or RAID system for archival purposes plus cloud storage for artefacts that are often fetches is a solution that has very low energy cost and allows enough flexibility to adapt for the near future. Regarding energy consumption, this is one area where technological improvements on energy efficiency can have a huge impact on energy costs related to long term preservation. Being able to apply all the learning to this new particular set of constraints is an area in itself that we believe is worth of further studying.

With the advent of new forms of art, such as video art or digital art works and also more interactive exhibits, screens are becoming more present in museums. As Chapter 5 presented, the energy efficiency of screens is improving over time. Studying their energy efficiency and the technologies behind them is important since any energy reduction will positively affect the museums' budget. Usually exhibitions that generate excess of heat are the ones who waste most of the energy. Also with the advent of new devices such as tablets or mini computers, making media exhibits is becoming easier and cheaper since these devices have smaller sizes and are very energy efficient. It also provides more ways to improve the energy footprint of such installations, since generated heat is kept low and the HVAC system can run more efficiently. Although switching could be a big hurdle for some museums due to the number of exhibits that have to be renewed but in the long term it will definitely help. Smaller museums should definitely embrace these types of devices and due to their low cost and maintenance, they are a great start for expanding their audience by providing more interactive and engaging exhibits.

In Chapter 6, a survey was presented about the views of three different museums on the green ICT topic related to museums. This was definitely one of the most challenging chapters due to the scope of this thesis. We would like to thank again all the participants. Museums keep track the cost of their energy bills and investigate measures to reduce them. We were glad that some museums helped us to better understand this topic from their point of view. It definitely improved our understudying of the subject at hand and gave us a better perspective. A survey with more museums (including others around Europe) was planned but due to time constraints and the difficulty to prepare them, it was not possible in the end. We still think that a good way to study this subject is to directly interview museums on how they will adapt to the needs of improving their energy efficiency.

At last, museums are noticing more and more how technology can help them improve their activities. Nowadays, all museums have acknowledge the importance of technology and how it helps enhancing museum visitors. We believe that the next step is museums to notice how technology can also help other areas like digitisation, long term preservation and media exhibits in the area of energy efficiency.

7.1 Future work

In this section we will describe some future work that would definitely help to further study and comprehend the topic green ICT and museums.

A major step forward would be establishing a partnership with a museum so more detailed energy consumption can be recorded and studied. Although a total full cooperation with large museums might be quite hard to agree, smaller museums may be more open to the idea. A downside would be the size of the museum, though if it has interesting energy consumption characteristics or they are more willing to collaborate than others it could be a very important step to show the project to bigger museums.

As we mentioned in Chapter 4, long term preservation will be a major task that all museums will eventually have to accomplish. Studying in a more detailed way the storage options available now and the ones that will come in the near future is very necessary since technologies can help improve the energy efficiency of these practices. Also, there are frameworks available for long term preservation, evaluating the different storage options and the suitability of the framework could be a very interesting perspective worth of studying.

The survey was one of the most important parts of this thesis. Expanding the survey to include more museums (even abroad from Finland) is needed if we want to have a bigger and better picture of the situation. Although some museums publish plans and try to be very open about their activities, sometimes these efforts lack of certain depth, making interviewing them one of the only ways to get specific data that was not covered on the plans. Also, smaller museums are a big part of the museum ecosystem and some of them can be more open to change or participate in pilot programs than larger consolidated museums so their needs and practices should also be addressed too.

Museums are organisations that have very long lives, the practices they adopt and investments they make in conserving energy, digitising and storing their collections and making those digitally accessible, and adopting green ICT practices are worth following and further study.

Finally, as technology always advances (both new features and improved energy consumption), we feel there could be topics or areas we haven't thought of yet where ICT generally and green ICT in particular will help museums in the future.

Bibliography

[1] Interview at Ateneum with Kari Peiponen. Private interview, March 17 2014.

[2] Interview at Gallen-Kallela Museum with Tuija Wahlroos. Private interview, May 13 2014.

[3] Interview at Heureka Science Centre with Mika Huovinen. Private interview, April 28 2014.

[4] Appel, S. Copyright, digitization of images, and art museums: Cyberspace and other new frontiers. *UCLA Ent. L. Rev. 6* (1998), 149.

[5] Armbrust, M., Fox, A., Griffith, R., Joseph, A. D., Katz, R., Konwinski, A., Lee, G., Patterson, D., Rabkin, A., Stoica, I., et al. A view of cloud computing. *Communications of the ACM 53*, 4 (2010), 50–58.

[6] Ascione, F., Bellia, L., Capozzoli, A., and Minichiello, F. Energy saving strategies in air-conditioning for museums. *Applied thermal engineering 29*, 4 (2009), 676–686.

[7] Barbosa, C. C. Innovation in museums through the use of icts.

[8] Beagrie, N. *National digital preservation initiatives.* DIANE Publishing Company, 2003.

[9] Bostoen, T., Mullender, S., and Berbers, Y. Power-reduction techniques for data-center storage systems. *ACM Computing Surveys (CSUR) 45*, 3 (2013), 33.

[10] Bowen, J., Bradburne, J., Burch, A., Dierking, L., Falk, J., Fantoni, S. F., Gammon, B., Giusti, E., Gottlieb, H., Hsi, S., et al. *Digital technologies and the museum experience: Handheld guides and other media.* Rowman Altamira, 2008.

[11] Chapman, S. Counting the costs of digital preservation: is repository storage affordable? *Journal of digital information 4*, 2 (2006).

[12] Charitonos, K., Blake, C., Scanlon, E., and Jones, A. Museum learning via social and mobile technologies:(how) can online interactions enhance the visitor experience? *British Journal of Educational Technology 43*, 5 (2012), 802–819.

[13] Cignoni, P., and Scopigno, R. Sampled 3d models for ch applications: A viable and enabling new medium or just a technological exercise? *Journal on Computing and Cultural Heritage (JOCCH) 1*, 1 (2008), 2.

[14] Coyle, K. Mass digitization of books. *The Journal of Academic Librarianship 32*, 6 (2006), 641–645.

[15] D'Amato, F., Gamba, P., and Goldoni, E. Monitoring heritage buildings and artworks with wireless sensor networks. In *Environmental Energy and Structural Monitoring Systems (EESMS), 2012 IEEE Workshop on* (2012), IEEE, pp. 1–6.

[16] Díaz, L., and Partanen, L. Digital cultural heritage to support novel activities in the classroom of the future. *Classroom of the future: Orchestrating collaborative spaces* (2010), 183–197.

[17] Englert, F., El'Hindi, A., Burgstahler, D., Alhamoud, A., and Steinmetz, R. Reducing the electricity consumption of large-outdoor led advertising screens. In *Proceedings of the 5th international conference on Future energy systems* (2014), ACM, pp. 209–210.

[18] Falk, J. H. *Identity and the museum visitor experience.* Left Coast Press, 2009.

[19] Feeney, M. *Digital culture.* National Preservation Office, 1999.

[20] Ghiani, G., Paternò, F., Santoro, C., and Spano, L. D. Ubicicero: A location-aware, multi-device museum guide. *Interacting with Computers 21*, 4 (2009), 288–303.

[21] Guerra, J., Belluomini, W., Glider, J., Gupta, K., and Pucha, H. Energy proportionality for storage: Impact and feasibility. *ACM SIGOPS Operating Systems Review 44*, 1 (2010), 35–39.

[22] Haywood, N., and Cairns, P. Engagement with an interactive museum exhibit. In *People and Computers XIXÑThe Bigger Picture*. Springer, 2006, pp. 113–129.

[23] Hedstrom, M. Digital preservation: a time bomb for digital libraries. *Computers and the Humanities 31*, 3 (1997), 189–202.

[24] Hinton, K., Baliga, J., Feng, M. Z., Ayre, R., and Tucker, R. Power consumption and energy efficiency in the internet. *Network, IEEE 25*, 2 (2011), 6–12.

[25] Huhtamo, E. On the origins of the virtual museum. In *Nobel Symposium on" Virtual Museums and Public Understanding of Science and Culture". Stockholm, Sweden, In R. Parry (Eds.) Museums in a Digital Age. Oxon & New York: Routledge* (2002), pp. 121–135.

[26] Iyer, S., Luo, L., Mayo, R. N., and Ranganathan, P. Energy-adaptive display system designs for future mobile environments. In *MobiSys* (2003), vol. 3, pp. 245–258.

[27] Johnson, L., Adams, S., and Witchey, H. The nmc horizon report: 2011 museum edition. *Austin, Texas: The New Media Consortium* (2011).

[28] Khalfaoui, S., Seulin, R., Fougerolle, Y., and Fofi, D. An efficient method for fully automatic 3d digitization of unknown objects. *Computers in Industry 64*, 9 (2013), 1152–1160.

[29] Levy, D. M. Heroic measures: reflections on the possibility and purpose of digital preservation. In *Proceedings of the third ACM conference on Digital libraries* (1998), ACM, pp. 152–161.

[30] Li, R., Luo, T., and Zha, H. 3d digitization and its applications in cultural heritage. In *Digital Heritage*. Springer, 2010, pp. 381–388.

[31] Liu, K. Designing visitor experience for open-ended creative engagement in art museums: A conceptual multi-touch prototype design.

[32] Lopatin, L. Library digitization projects, issues and guidelines: A survey of the literature. *Library hi tech 24*, 2 (2006), 273–289.

[33] Masaoka, K., Nishida, Y., Sugawara, M., Nakasu, E., and Nojiri, Y. Sensation of realness from high-resolution images of real objects. *IEEE transactions on broadcasting 59*, 1 (2013), 72–83.

[34] Mell, P., and Grance, T. The nist definition of cloud computing. *National Institute of Standards and Technology 53*, 6 (2009), 50.

[35] Mueller, H. F. Energy efficient museum buildings. *Renewable Energy 49* (2013), 232–236.

[36] Park, W. Y. Tv energy consumption trends and energy-efficiency improvement options.

[37] Patterson, D. A., Gibson, G., and Katz, R. H. *A case for redundant arrays of inexpensive disks (RAID)*, vol. 17. ACM, 1988.

[38] Pérez-Lombard, L., Ortiz, J., and Pout, C. A review on buildings energy consumption information. *Energy and buildings 40*, 3 (2008), 394–398.

[39] Poole, N. The cost of digitising europe's cultural heritage. Survey report, Comité des Sages of the European Commission, November 2010.

[40] Rabinovici-Cohen, S., Marberg, J., Nagin, K., and Pease, D. Pds cloud: Long term digital preservation in the cloud. In *Cloud Engineering (IC2E), 2013 IEEE International Conference on* (2013), IEEE, pp. 38–45.

[41] Roberts, C. The wits digitisation experience: Lessons learned and suggestions for national collaboration.

[42] Rosenthal, D. S., Rosenthal, D. C., Miller, E. L., Adams, I. F., Storer, M. W., and Zadok, E. The economics of long-term digital storage. *Memory of the World in the Digital Age, Vancouver, BC* (2012).

[43] Sandifer, C. Technological novelty and open-endedness: Two characteristics of interactive exhibits that contribute to the holding of visitor attention in a science museum. *Journal of Research in Science Teaching 40*, 2 (2003), 121–137.

[44] Sankar, K. P., Ambati, V., Pratha, L., and Jawahar, C. Digitizing a million books: Challenges for document analysis. In *Document Analysis Systems VII*. Springer, 2006, pp. 425–436.

[45] Shi, X., Lu, D., and Diao, C. An ultra large area scanner for ancient painting and calligraphy. In *Advances in Multimedia Information Processing-PCM 2008*. Springer, 2008, pp. 846–849.

[46] Smithsonian. Digitization strategic plan. Tech. rep., Smithsonian Insitution, 2010.

[47] Srinivasan, R., Boast, R., Furner, J., and Becvar, K. M. Digital museums and diverse cultural knowledges: Moving past the traditional catalog. *The Information Society 25*, 4 (2009), 265–278.

[48] Stroeker, N., and Vogels, R. Digitisation in european cultural heritage institutions. Survey report, ENUMERATE, May 2012.

[49] Stroeker, N., and Vogels, R. Digitisation in european cultural heritage institutions. Survey report, ENUMERATE, January 2014.

[50] Styliani, S., Fotis, L., Kostas, K., and Petros, P. Virtual museums, a survey and some issues for consideration. *Journal of cultural Heritage 10*, 4 (2009), 520–528.

[51] Tanner, S. Librarians in the digital age: planning digitisation projects. *Program: electronic library and information systems 35*, 4 (2001), 327–337.

[52] Templeton, C. A. Museum visitor engagement through resonant, rich and interactive, 2011.

[53] Tesoriero, R., Gallud, J., Lozano, M., and Penichet, V. Enhancing visitorséxperience in art museums using mobile technologies. *Information Systems Frontiers* (2012), 1–25.

[54] Todorov, T. Y., Bogdanova, G. T., and Noev, N. Digitization and 3d scanning of historical artifacts. *Digital Presentation and Preservation of Cultural and Scientific Heritage*, III (2013), 133–138.

[55] Tsai, H., and Sung, K. Mobile applications and museum visitation. *Computer 45*, 4 (2012), 95–98.

[56] Van Schijndel, A., and Schellen, H. L. Application of an integrated indoor climate & hvac model for the indoor climate performance of a museum. *International Journal for Restoration of Buildings and Monuments 9*, 5 (2006), 219–228.

[57] Viani, F., Salucci, M., Rocca, P., Oliveri, G., and Massa, A. A multi-sensor wsn backbone for museum monitoring and surveillance. In *Antennas and Propagation (EUCAP), 2012 6th European Conference on* (2012), IEEE, pp. 51–52.

[58] Vom Lehn, D., and Heath, C. Accounting for new technology in museum exhibitions. *International Journal of Arts Management* (2005), 11–21.

[59] Waters, D., and Garrett, J. *Preserving Digital Information. Report of the Task Force on Archiving of Digital Information.* ERIC, 1996.

[60] Wheatley, P. Migration: a camileon discussion paper. *Ariadne 29*, 2 (2001).

[61] Wright, R., Miller, A., and Addis, M. The significance of storage in the "cost of risk" of digital preservation. *International Journal of Digital Curation 4*, 3 (2009), 104–122.

[62] Yeung, T. A. *Digital preservation: best practice for museums.* Canadian Heritage Information Network, 2004.

Appendix A

Survey appendix

Aalto University

Museums & Green ICT Study

Background

The **Green ICT** research project at Aalto University studies energy consumption and emissions from the use of Information and Communication Technology (ICT) in different organizations and industries:

http://energyscience.aalto.fi/en/research/projects/green_ict

The energy consumption and emissions from Information and Communication Technology (ICT) is globally equivalent to that of air traffic, and is growing rapidly. The main goal of the **Green ICT** research project within Aalto University's Energy Science Initiative is to find innovative techno-socioeconomic solutions that could lead to a major energy and environmental impact.

As part of its work, the Green ICT research program is interested in studying energy consumption patterns in **museums**. Museums are interesting to study because they are long-lived institutions of great importance to society in conserving and presenting cultural heritage, and because sustainability in the energy needed to maintain and present their assets both physically and through the use of ICT technologies into the longer-term future may be an organizationally important objective. Setting sustainability objectives for their operations is an increasingly important objective for some museums, such as the Smithsonian and the Victoria and Albert museums.

Research Questions

These are some of the research questions the project would like to address:

- What is the breakdown of energy consumption at examples of several different types of museums?
- How does the energy consumption from use of ICT compare to non-ICT energy usage?
- How to quantify and measure energy consumption for ICT-intensive processes such as:
    - Content digitization
    - Storage of digital collections
    - Electronic media displays & exhibits
    - Digital signage

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    - Mobile, web and social networking services
    - Other

Approach

We would like to begin by conduct a short personal interview with IT or facility managers at a fewinterested museums to better quantify and understand this topic.

This could lead into a more detailed set of questions and analysis depending on the level of interest. With the institution's permission, the results could be used as input to Master's Thesis and PhD work that is underway at Aalto in this area.

The research's findings could lead to an understanding of how to achieve energy savings by participants to the research.

The teams working on this study are:

- Aalto University, School of Science, Dept. of Computer Science and Engineering:
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Museums & Green ICT Study:

Questions

Introduction

Q1 Can you tell a bit about your role and responsibilities at the museum?

Understanding overall energy consumption

Museum energy consumption

Q2.1 Does the museum monitor its energy costs (for example energy bills) over time (e.g. monthly, quarterly or annually)? Can you tell a bit about how it does that?

Q2.2 Are energy bills paid out of the museum's overall budget?

Q2.3 Does the museum track its energy consumption over time? (For example electrical usage is often measured in kilowatt-hours.)

> Q2.3.1 Does the museum make a breakdown of any energy costs or consumption according to the type (electricity, lighting, A/C, Humidification, heating, computing)? If so, what are the relative sizes?
>
> Q2.3.2 Is information technology a significantly large part of the energy costs?
>
> Q2.3.3 Has the museum ever monitored energy consumption of any its IT equipment (computers, displays, projectors, etc.)?

Q2.4 Does the museum's own staff maintain the building's facilities?

Q2.5 How much of the museum's space is used as public exhibition space, versus private office space, internal operations, etc.?

Sustainability planning

Q2.5 "Sustainability" is a concept meaning to have a goal of not being harmful to the environment or depleting natural resources, and thereby supporting long-term

ecological balance. Does the museum have any formal planning for improving the sustainability of its operations?
Q2.6 Does the museum (e.g. management board, annual plan) set annual targets for reducing energy consumption or costs? How are those targets tracked?

Q2.7 Does the museum consider power consumption when buying new equipment?

Understanding digital media energy consumption

Digital media exhibits

Q3.1 How many "digital media" exhibits (exhibits using large screens or projectors) does the museum have running / shown annually?
- Q3.1.1 How long do they run for on average? (weeks? months? longer?)
- Q3.1.2 Which is used most often: large screen displays or projectors?

Digital media storage

Q3.2 Does the museum digitize and store digital pictures (or 3D scans) of any museum artifacts?
- Q3.2.1 How are the digital copies stored? on tape? on hard disks?
- Q3.2.2 Are the digital copies stored in network/cloud storage?
- Q3.2.3 How many items totally in the digital collection now?
  - In number of items?
  - In gigaBytes of diskspace?
- Q3.2.4 How many new items are digitized and stored per year?

Web presence

Q3.3 Does the museum regularly track its web traffic statistics? How much web traffic (e.g. GBs) was there over the last year?

Ending

Q4.1 Do you have any final thoughts or questions?

Q4.2 Do you think there are any important questions or topics for you, that were not asked?